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Development of Programmable Embroidery Pressure Sensors

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***Abstract*—This paper presents a new class of programmable embroidered pressure sensors on cloth for textile electronics leveraging interdigitated capacitor designs. Our work demonstrates the fabrication procedure for programmable embroidered capacitive and resistive sensors through the integration of conductive yarns into fabric substrates, thus engendering flexible pressure sensors. The experimental findings heightened sensitivity and rapid response to applied force in the developed sensors, showcasing their potential for various applications in wearable technology and smart textiles.**

***Index Terms*—textile electronics, programmable embroidery, textile sensors, force sensor.**

I. Introduction

Wearable sensors play a significant role in our daily lives nowadays across many applications, from activity tracking to health monitoring [1]. In these applications for daily use, the demand for wearable sensors in terms of flexibility and comfort is increasing [2]. Textile sensors, crafted from conductive yarns and fabrics through embroidery, offer a novel approach to creating soft, flexible, and wearable sensors capable of detecting touch, force, pressure [3], and motion [4]. Various fabrication techniques have been explored to develop these textile sensors, including screen printing, inkjet printing, and, especially, embroidery processes. For designing and fabricating embroidery sensors, manual processes are commonly used [5]. However, this brings challenges to the sensor's reliability, accuracy, stability, and production time when dealing with fabrication factors including geometric complexities, stitching patterns, thread tension, and material properties [6]. An automatic and programmable embroidery method is needed for developing more reliable wearable sensors with more stable performance.

The goal of this study is to develop programmable embroidery pressure sensors on fabric with conductive yarn for wearable use. We fabricated two types of sensors, capacitive and resistive, for pressure sensing. We performed the experimental setup to measure the sensor results concerning the applied force and the sensitivity of both sensors. In the following sections, we include the fabrication, experimental procedure, and results, followed by a conclusion.

II. Fabrication and Results

This study highlights the designing and manufacturing parameters, from the selection of conductive yarn, and resistive fabric, to generation of stitching, and geometric parameters for the performance of sensors. The embroidery technique offers unique advantages for the customization and integration of textiles, making it a promising method for creating textile sensors. In this study, we design the pressure sensors using geometric parameterization, such as choosing the desired length, space, and stitching patterns and then create the digitizing machine code using Python. After the software processes, the next steps involve fabricating and finalizing sensors. To choose a compatible material with the embroidery machine, we found that HC-40 [7] fits our requirements on performance and sensitivity because of its strength and resistive properties. The overview of fabricating textile wearable sensors has been shown in Fig. 1.

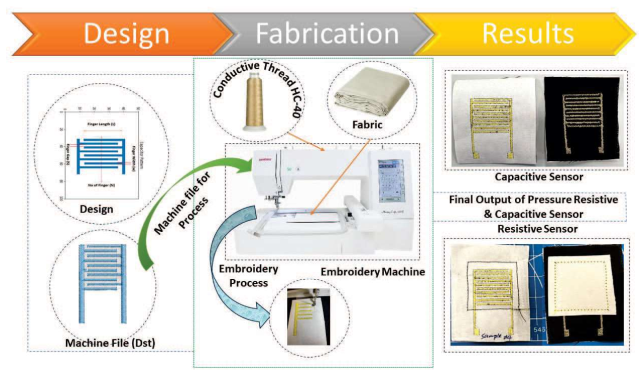

Fig. 1. Designing and Fabrication Process for Textile Sensors.

The setup for evaluating the performance of embroidered pressure sensors is illustrated in Fig. 2. Displacement between the sensor and a reference point is measured using a distance meter, while the applied force is gauged with a force gauge. During testing, the force is applied through a 3D-printed (110mm × 120mm × 20mm) flat plate. The resistance is measured using a digital meter (MM300), and the output results of the capacitance sensor is measured using an LCR meter (Matrix LCR 5200).

The three samples of capacitive sensors, labeled S-1, S-2, and S-3, were fabricated as shown in Fig. 3, which illustrates the relationship between capacitance and applied force. Initially, before reaching the cutoff region (35N), the results show small deviations due to gauge sensitivity. As the applied force

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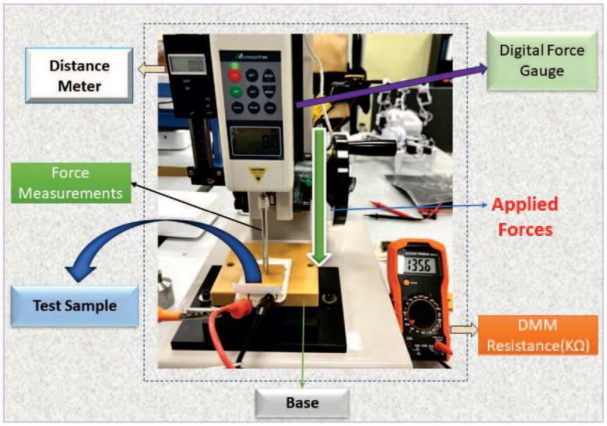

Fig. 2. Experimental setup for the measurements.

crosses the cutoff point, the results demonstrate a smooth and linear response. The force applied to each sensor shows unique responses corresponding to the increments in applied force, indicating a smooth and more linear response and providing a comprehensive representation of the dynamic sensitivity of the sensor to applied forces.

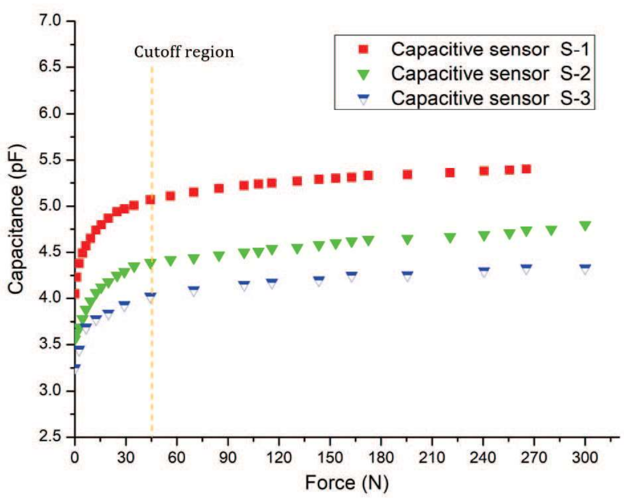

Fig. 3. Experimental Result Capacitive vs Force.

The relationship between resistance and applied force of four resistive sensors has been presented in Fig. 4. These resistive sensors show high resistance near zero force. As the force gradually increases, the resistance decreases and reaches the cutoff points (5N to 20N) with a non-linear response to the applied forces. Beyond the cutoff region, the response of each sensor to applied force becomes more linear and smooth, indicating an inverse relationship between force and resistance. Eventually, the resistance for each sample reaches the minimum desired resistance within the applied force range (120N). These research findings demonstrate the force sensitivity of the resistors, with similar responses to the applied force.

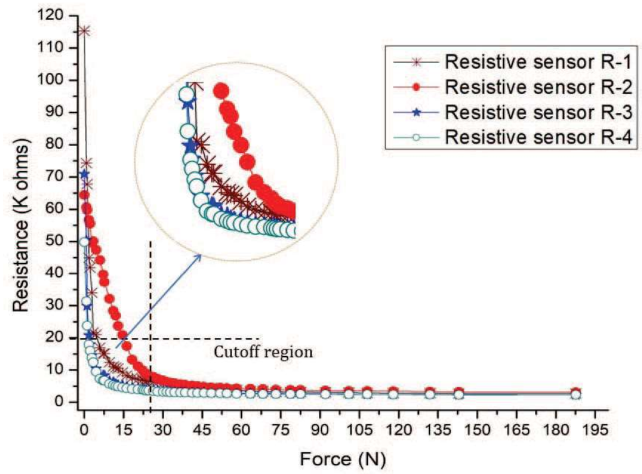

Fig. 4. Experimental Result Resistive vs Force.

III. Conclusion

The integration of wearable electronic devices has revolutionized daily life, with smart textiles offering flexible and comfortable solutions. Embroidered pressure sensors, utilizing both resistive and capacitive methods, combine traditional textile techniques with modern sensor technology, where the sensitivity of the sensors depends upon the geometric parameters, stitching patterns, thread tension, and material properties. The results of capacitive and resistive sensors demonstrate smooth responses with respect to the applied force, and each sensor exhibits a unique sensitivity response. These research findings highlight the potential of embroidered pressure sensors in wearable technology, offering promising enhancements in health monitoring applications.

Acknowledgment

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