Printed Soft Capacitive Sensor for Fingertip Contact Monitoring

Paolo Bellitti, Michela Borghetti, Emilio Sardini, Mauro Serpelloni
Department of Information Engineering
University of Brescia
Brescia, Italy
michela.borghetti@unibs.it

***Abstract*— This study presents a low-cost, highly customizable wearable capacitive sensor for measuring contact force and pressure, particularly those exerted by fingertips against objects. The sensor fabrication process leverages additive manufacturing technologies, including Fused Filament Fabrication (FFF) and Aerosol Jet Printing (AJP), enabling integration into gloves and garments. The experimental setup involved impedance measurements to characterize the sensor electrical behavior and mechanical testing to evaluate its response under cyclic loading and varying environmental conditions. The results demonstrate a consistent capacitive response to applied forces, with a sensitivity of about 2.07 pF/N and a resolution below 0.5 N. The sensors exhibited excellent repeatability and rapid recovery times of less than 10 seconds. Furthermore, temperature-dependent measurements revealed a capacitance variation of -0.04 pF/°C, which suggests the need for thermal compensation in applications with significant temperature fluctuations. These findings indicate that the proposed capacitive sensor is suitable for real-world applications, such as force measurement in industrial settings and wearable human-machine interfaces.**

Keywords—capacitive sensor, force sensor, printed sensor, fingertip force

I. Introduction

Assessing the biomechanical interactions between the human hand and external objects is critical in various fields, particularly in industrial applications and worker safety [1]. In manufacturing and manual labor environments, monitoring fingertip forces during gripping activities is essential for preventing musculoskeletal injuries [2], optimizing ergonomics [3], enhancing overall productivity [4], and facilitating human-robot collaboration [5]. The integration of wearable sensing technologies into protective gloves provides real-time feedback on worker strain, ensuring compliance with safety standards and reducing fatigue-related risks. A key development in this area is the implementation of smart wearable gloves equipped with unobtrusive, lightweight sensors capable of continuously monitoring hand pressure and grip force [6]. These gloves provide real-time insights into a worker's physical effort, enabling data-driven ergonomic improvements and early detection of strain-related conditions, and advancements in telemanipulation. Unlike traditional monitoring systems, which may be cumbersome or restrictive [7], printed sensors offer a seamless integration into daily tasks without impeding dexterity or comfort. The demand for such wearable technologies has driven research into novel sensing solutions that prioritize flexibility, durability, and accuracy in force measurement [8].

Recent advancements in printed electronics, particularly through Aerosol Jet Printing (AJP), have enabled the fabrication of conductive traces and sensors directly onto flexible substrates, including fabrics and irregularly shaped objects. This technology is promising for the integration of flexible sensors into garments and soft structures, ensuring continuous and non-intrusive monitoring of body interactions [8]–[10].

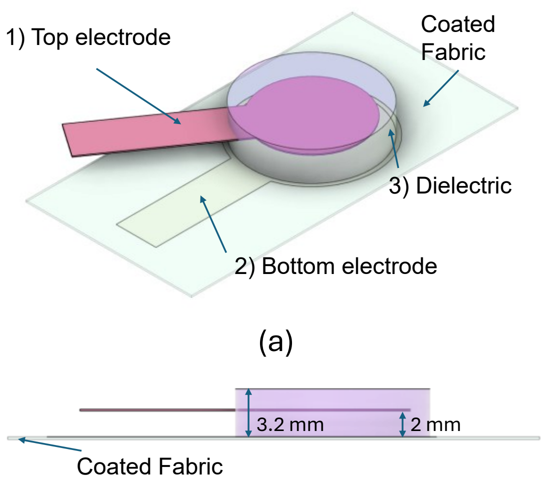
Pressure transducers explored over the years can be based on piezoresistive [11], piezoelectric [12], capacitive [13], and optical [14] principles. Traditional force sensors employed in these studies mainly rely on resistive or piezoresistive [15]technologies, which, despite their widespread use, exhibit limitations such as mechanical rigidity, sensitivity constraints, and reduced adaptability to curved or irregular surfaces. Additionally, their response is affected by temperature variations and long-term mechanical fatigue, leading to signal drift over time and reduced measurement reliability. Various piezoresistive sensors reported in the literature suffer from signal degradation under prolonged use, necessitating frequent recalibrations to maintain accuracy. Examples include thin-film force-sensitive resistors (FSRs) commonly used in commercial wearable applications, but their accuracy and long-term stability remain a challenge. Capacitive pressure sensors are particularly attractive due to their high sensitivity, excellent repeatability, low power consumption, and their ability to operate independently of temperature variations [16]. Several studies have demonstrated the feasibility of printed capacitive sensors for force measurement. Unlike resistive sensors, capacitive sensors operate by detecting variations in the electrical capacitance induced by mechanical deformation of a dielectric material. This principle allows for the development of soft, flexible, and highly responsive sensors that can be easily integrated into wearable systems. For instance, in [17], a flexible capacitive sensor fabricated using inkjet printing was proposed to measure wound healing. This capacitive sensor was printed on polyimide and then integrated on a dressing, served as the dielectric layer, and used to measure ankle movements.

Recent research has demonstrated the feasibility of capacitive sensors for soft robotic applications or for measuring multiple quantities. For example, in [18], a capacitive pressure sensor and an electrochemical sensor were developed to monitor both the pressure and hazardous materials using screen printing technology. However, specifically low-cost sensors for evaluating user comfort and grip force in real-world activities remain relatively unexplored. Addressing this gap, the present study focuses on the development and characterization of a novel capacitive force sensor specifically designed for wearable applications. This study aims to explore the possibility of developing a low-cost wearable hybrid parallel-plate capacitive sensor capable of measuring forces in the range of 0-20 N, as this force range corresponds to typical grip forces exerted by human fingers when handling objects of various shapes and stiffness levels [15]. The proposed sensor consists of printed electrodes with an interposed dielectric material, leveraging printed electronics techniques to ensure flexibility and adaptability to different applications. The aim of the work is to propose a simple and low-cost fabrication process for designing wearable force sensors to be easily integrated into gloves and garments. Compared to previous studies [19], which primarily presented conceptual designs and a preliminary prototype, this work aims 1) to improve the performance by optimizing the fabrication of the electrodes and 2) to provide an extended characterization of the fabricated sensors. By combining textile integration, precision additive manufacturing, and strategic structural reinforcement, this fabrication process is low-cost, simple, and reproducible. Furthermore, it successfully enables the fabrication of capacitive sensors suitable for wearable applications. The fabrication process of both electrodes is based on using AJP, ensuring high adaptability and conformability. Furthermore, a refined characterization methodology is applied to assess the sensor mechanical response, including sensitivity, reproducibility, and hysteresis. A thermal characterization evaluates the sensor response under varying environmental conditions, ensuring reliability in different usage scenarios.

The paper is structured as follows: Section 2 describes the sensor design and fabrication process, detailing the materials, structure, and manufacturing techniques employed. Section 3 described the experimental equipment, and the tests used for the sensor characterization. Section 4 presents and discusses the experimental results, including sensitivity analysis, response under different loads, assessment of hysteresis effects, and thermal effect on the sensor response.

II. Design and Fabrication

The capacitive sensor fabrication involved multiple steps, integrating textile printing and advanced deposition techniques. The process was inspired by the methodology described in [19], with modifications aimed at simplifying the fabrication process, particularly in the top electrode fabrication. The schematic structure of the parallel-plate capacitance sensor is illustrated in Fig. 1a and b; each component is numbered according to the fabrication steps detailed in Section IIB, and material details are described in Section IIA.



(a)

(b)

Fig. 1. a) Schematics and b) cross-section of the printed capacitive sensor. The three components are numbered according to the fabrication/assembly sequence.

A. Materials

The bottom electrode was fabricated using a high-performance stretchable fabric composed of 71% polyamide and 29% elastane, chosen for its comfort, form-fitting properties, and unobtrusiveness in wearable applications. A polyurethane primer was screen-printed onto the textile to improve surface smoothness and ensure compatibility with the subsequent conductive layers. The top electrode was supported by a 125-µm-thick polyimide substrate, selected for its mechanical robustness and thermal stability, making it well-suited for flexible electronics. Both electrodes were printed using Genesink Smart Aero S-CS61308, a silver nanoparticle-based ink. The dielectric layer was formed using Elite Double 8 by Zhermac Dental, with a mold fabricated from polylactic acid (PLA) filament. Elite Double 8 is an addition silicone typically used in dental applications for its high dimensional stability and excellent elastic recovery. CircuitWorks Conductive Epoxy CW2400 was employed to establish electrical connections between the conductive traces and the 32-AWG wire used for impedance measurements. LOCTITE 406 adhesive was applied to bond the dielectric layer to the top electrode.

B. Fabrication Process

The electrodes were printed using an AJ-300 Aerosol Jet Printer (Optomec, Albuquerque, NM, USA). The electrode layout (depicted in Fig. 1a) was designed using AutoCAD software. The bottom electrode featured a circular shape with a diameter of 16 mm, accompanied by a conductive trace measuring 14 mm × 5 mm. The top electrode followed the same design but with a reduced diameter of 13 mm. The printing parameters were set as follows:

- Plate speed: 2 mm/s
- Sheath gas flow: 400 standard cubic centimeters per minute (SCCM)
- Atomizer gas flow: 610 SCCM
- Exhaust gas flow: 605 SCCM

To ensure adequate conductivity, the printing process was repeated three times. Following deposition, the electrodes were sintered using a flash lamp annealing process. The top electrode, printed on polyimide, was subsequently laser-cut to ensure high precision and edge definition. The dielectric layer was fabricated as described in [19]. A custom circular mold with an inner diameter of 15 mm and a depth of 3.2 mm was created using fused filament fabrication (FFF) with PLA. To facilitate the integration of the top electrode within the dielectric layer, four 2-mm-tall pillars were incorporated at the bottom of the mold, ensuring that the top electrode was embedded at a depth of 1.2 mm within the silicone, and 2 mm from the bottom electrode. This design provides protection against environmental exposure and mechanical wear during contact with objects. The silicone-based structures were cured at room temperature for 24 hours. After curing, the dielectric layer was bonded to the bottom electrode, and the conductive glue was used to secure the electrical connections.

An example of the final assembled sensor is shown in Fig. 2. At the end of the fabrication process, three sensors were successfully fabricated and labeled as Sensor #1, Sensor #2, and Sensor #3.

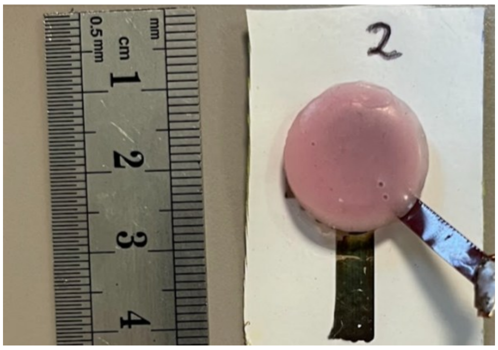


Fig. 2. Example of a printed capacitive sensor.

III. Experimental Setup and Procedure

An MFIA 500 kHz Impedance Analyzer, interfaced with a laptop, was used to measure the electrical impedance of the sensors. The frequency analysis ranged from 1 kHz to 510 kHz, with 100 logarithmically spaced sampling points. The proposed sensor was modeled as a simple two-element system, consisting of a capacitor (Cp) in parallel with a resistor (Rp), as confirmed both theoretically and experimentally. For characterization, the impedance analyzer provided the equivalent capacitance (C) and resistance (R) values every 0.02 s, with measurements taken at a reference frequency of 50 kHz.

A Mark-10 force test stand, equipped with a 250 N load cell, was used for uniaxial compression tests. The tests were conducted at room temperature on the three sensor specimens, following these protocols:

- Test #1: Two load-unload cycles from 0 N to 25 N, with a crosshead speed of 0.2 mm/min. A 10-second waiting period was included between cycles to account for the viscoelastic behavior of the dielectric layer.
- Test #2: Stress-relaxation at 25 N for 4 minutes. The crosshead was moved at 0.25 mm/min until reaching 25 N, at which point it was held in place, and the force decay was recorded for 5 minutes.
- Test #3: Twelve load-unload cycles from 0 N to 0.5 N, with a crosshead speed of 10 mm/min. The equivalent capacitance was recorded 10 seconds after each force setpoint (0 N and 0.5 N) was reached, and then the force was adjusted for subsequent measurements.

For each test, the load and crosshead displacement curves were recorded using the tensile system, while capacitance was measured by the MFIA 500 kHz Impedance Analyzer every 0.02 s. Additionally, the impedance variation of Sensor #1 as a function of temperature was analyzed (Test #4). The sensor was placed inside a climatic chamber where the temperature was varied from -20°C to 80°C in 10°C increments, with each step lasting 40 minutes.

IV. Results and Discussion

The impedance measurements of the three printed sensors within the frequency range of 1 kHz to 500 kHz confirmed that the equivalent electrical model, consisting of a capacitance (Cp) in parallel with a resistance (Rp), accurately represents the electrical behavior of the sensor, as shown in Fig. 3. Although slight variations were observed among the impedance responses of the three sensors, all exhibited a strong fit to the proposed electrical model. Since the Rp value exceeded 1 MΩ and remained relatively stable regardless of the applied load, Cp was chosen as the primary parameter for sensor characterization. The average capacitance calculated across the three fabricated sensors was 3.6 ± 0.1 pF, where 0.1 pF represents the maximum deviation from the mean value among the measured capacitances.

Under cyclic loading conditions (Test #1), the sensors exhibited elastic hysteresis due to the viscoelastic nature of the dielectric layer. The Young's modulus of the elastomer was estimated as 750 kPa based on the compression data obtained in Test #1. While silicone inherently exhibits viscoelasticity, this behavior does not compromise the repeatability of the sensor response, provided sufficient time elapses between repetitions. In this test, the compression speed was deliberately low, with each loading-unloading cycle lasting approximately 400 seconds, making the viscoelastic effects significant. As shown in Fig. 4, the load-displacement curve displays noticeable hysteresis. The results are related to Sensor #1, though the responses of all three sensors were comparable. Hysteresis is 30% of the maximum load when the displacement is 0.37 mm (corresponding to 11% of compression).

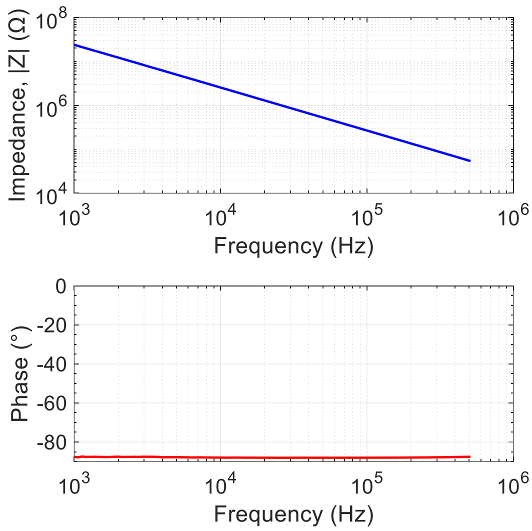


Fig. 3. Measured impedance response of Sensor #1, when no force is applied.

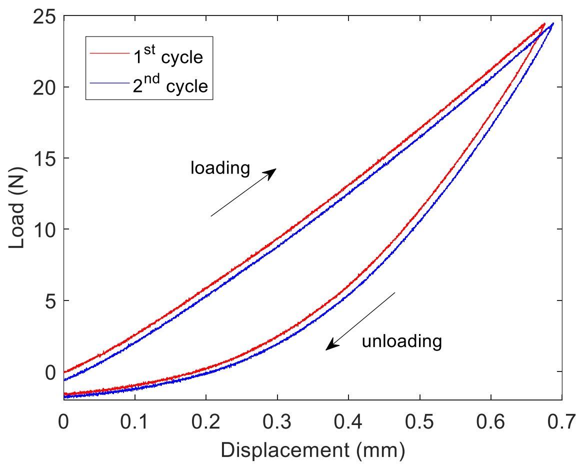


Fig. 4. Load-displacement curve of Sensor #1in the loading-unloading test (Test #1).

The recovery time was only a few seconds, as inferred from the observation that the mechanical behavior in the second cycle was nearly identical to the first.

Regarding the sensing response, the capacitance of capacitive sensors depends on multiple parameters, including the composition of the dielectric layer, the electrode area, and the inter-electrode distance. When a load is applied, the sensor undergoes compression, primarily altering the electrode distance. Compression was defined as the ratio of crosshead displacement to the initial dielectric layer thickness. The correlation between compression and capacitance is illustrated in Fig. 5. The maximum compression attained in Test #1 was 36%, corresponding to a capacitance change of 13.9%. Hysteresis was less pronounced in the capacitance-displacement curve compared to the capacitance-load curve, with an overall hysteresis of 3.5% across the entire range and less than 2% for compressions exceeding 3% (equivalent to a 2.5 N load). The relaxation time at 25 N found in Test #2 is 14%, as shown in Fig. 6. The response of the sensor in the loading of the sensor is the same as found in Test #1. In the phase where the transverse is kept fixed at 0.688 mm, the load recorded by the tensile machine decreases, as expected according to the viscoelastic behavior of the dielectric layer, while the capacitance value of the sensor is constant, as explained above.

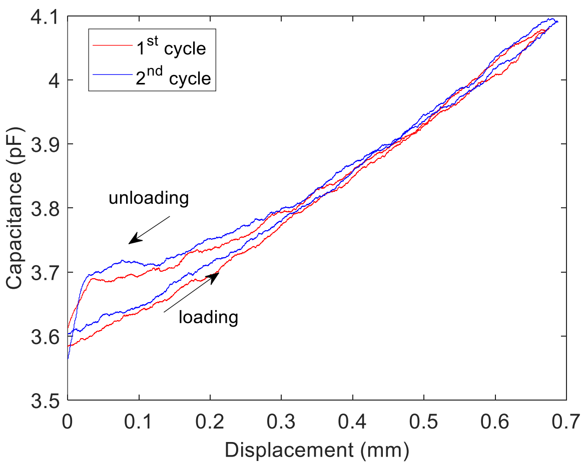


Fig. 5. Capacitance-displacement curve of Sensor #1in the loading-unloading test (Test #1).

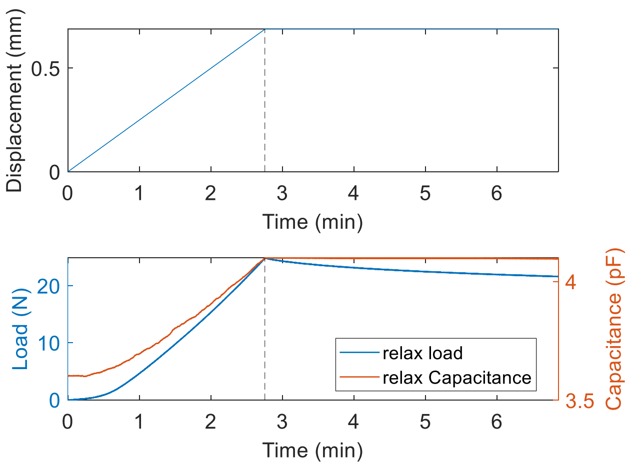


Fig. 6. Displacement (on the top), Capacitance, and Load (on the bottom) over time in Test #2.

By repeating the measurements of the capacitance at 0 N and 0.5 N (Test #3), the repeatability is ±0.01 pF, which is compatible with the accuracy of the instrumentation, as shown in Fig. 7. The standard deviation calculated on the measurements related to each repetition is less than 0.01 pF, and for this reason is not represented in the figure. The load of 0.5 N was selected to demonstrate the sensor's suitability for contact force sensing. For example, the force exerted by the fingertips on a keyboard ranges from 0.34 to 1.02 N, depending on the key type. Additionally, the recommended force for minimizing biomechanical strain on the arm muscles is 0.47 N [20]. Considering the results obtained from the Test #1, Test #2 and Test #3, capacitance-load curve can be approximated as a first-order relationship, as shown in Fig. 8. In this case, considering the target applications regarding grasping and fingertip contact, only the results obtained in the loading phase were considered. All sensors have the same response according to the load level. The sensitivity is (2.07±0.01) pF/N, and this result may confirm the good reproducibility of the fabrication process. The R-squared is 0.9978 in the case of Sensor #3, and 0.9993 in the case of Sensor #1 and Sensor #3.

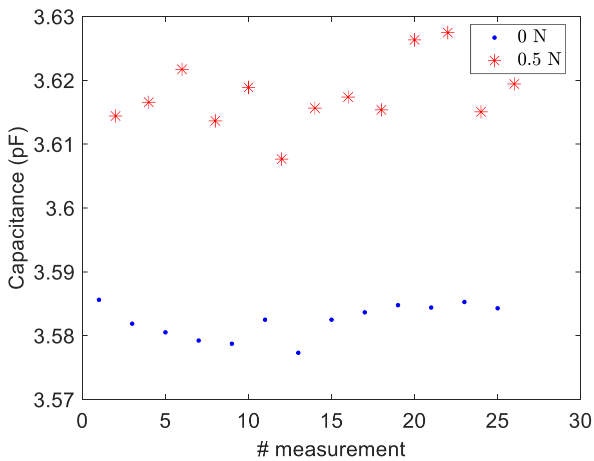


Fig. 7. Capacitance value of Sensor #1 according to the load level (0 N and 0.5 N) in twelve repetitions (Test #2). Each point is the mean value of the capacitance measurements taken in two seconds (100 measurements). The standard deviation is not represented because it is negligible in this representation.

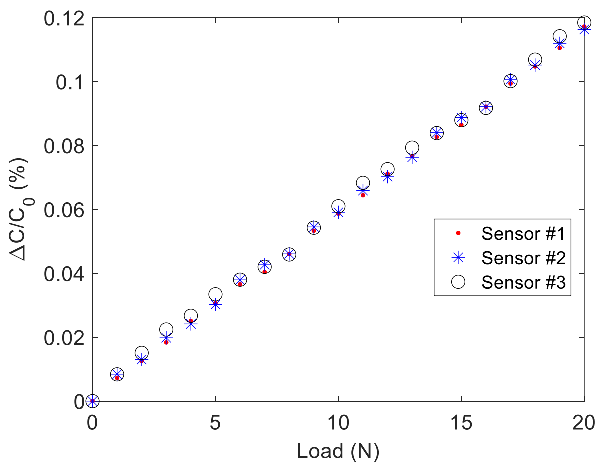


Fig. 8. Relative Capacitance change (related to the condition without load) according to the applied load for the three fabricated sensors in the loading-unloading test (Test #1), considering only the loading phase.

The results obtained from Test #4, shown in Fig. 9, indicate a correlation between the capacitance and the temperature. In this case, the capacitance decreased as temperature increased, with a sensitivity of -0.04 pF/°C, which remained consistent across multiple cycles. This behavior can be attributed to the permittivity change of the dielectric material with temperature variations. According to the specifications, this type of silicone is dimensionally stable. For example, literature confirms that polyvinyl siloxane, commonly used for dental impressions, maintains dimensional stability at different temperatures [21], [22]. In [23], a capacitive sensor based on silicone rubber exhibited a capacitance decrease of 0.025%/°C in the range from 24 °C to 44 °C.

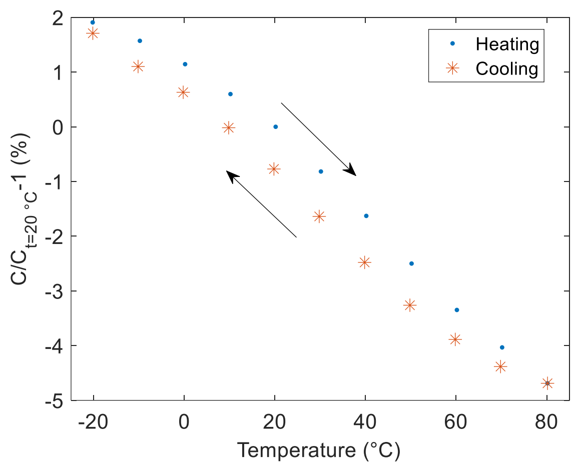


Fig. 9. Relative capacitance change (related to the capacitance at 20°C) of Sensor #1 in the heating and cooling phase.

V. CONCLUSIONS

This study proposes a low-cost and simple wearable capacitive sensor for measuring contact force and pressure, such as those exerted by fingertips against objects. The fabrication process is based on simple additive manufacturing technologies (FFF and AJP), enabling high customization in design and integration into clothing and gloves. Experimental results demonstrated that the proposed sensor can measure forces in the range from 0 N and 20 N, with a resolution of less than 0.5 N. The good sensitivity of 2.07 pF/N allows for the use of off-the-shelf capacitance-to-voltage converters in simple conditioning circuits. The recovery time was found to be less than 10 seconds. Furthermore, the fabrication process was highly reproducible, as indicated by the consistent performance of the three preliminary fabricated sensors. The capacitance change was also influenced by temperature; thus, in applications with large temperature variations, a temperature sensor could be integrated to compensate for the thermal effects. Future work will be focused on testing the capacitive sensor in real-world applications, particularly for measuring the fingertip force during industrial environments.

ACKNOWLEDGMENT

This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023), Spoke 5 "Light Vehicle and Active Mobility". This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

REFERENCES

[1] A. Ranavolo, F. Draicchio, T. Varrecchia, A. Silvetti, and S. Iavicoli, "Wearable Monitoring Devices for Biomechanical Risk Assessment at Work: Current Status and Future Challenges—A Systematic Review," *Int. J. Environ. Res. Public Health*, vol. 15, no. 9, 2018, doi: 10.3390/ijerph15092001.

[2] G. Zhou, M.-L. Lu, and D. Yu, "Investigating gripping force during lifting tasks using a pressure sensing glove system," *Appl. Ergon.*, vol. 107, p. 103917, 2023, doi: https://doi.org/10.1016/j.apergo.2022.103917.

[3] M. D. Alam and I. A. Khan, "Relation between grip force, ergonomic interventions, and task performance: a review," *Int. J. Interact. Des. Manuf.*, 2024, doi: 10.1007/s12008-024-02145-x.

[4] I. Kucukoglu, H. Atici-ulusu, T. Gunduz, and O. Tokcalar, "Application of the artificial neural network method to detect defective assembling processes by using a wearable technology," *J. Manuf. Syst.*, vol. 49, no. October, pp. 163–171, 2018, doi: 10.1016/j.jmsy.2018.10.001.

[5] A. Al-Yacoub, Y. C. Zhao, W. Eaton, Y. M. Goh, and N. Lohse, "Improving human robot collaboration through Force/Torque based learning for object manipulation," *Robot. Comput. Integr. Manuf.*, vol. 69, p. 102111, 2021, doi: https://doi.org/10.1016/j.rcim.2020.102111.

[6] S. Borik, A. Kmecova, M. Gasova, and M. Gaso, "Smart Glove to Measure a Grip Force of the Workers," *2019 42nd Int. Conf. Telecommun. Signal Process.*, pp. 383–388, 2019.

[7] M. Noghabaei and K. Han, "Automation in Construction Object manipulation in immersive virtual environments : Hand Motion tracking technology and snap-to-fit function," *Autom. Constr.*, vol. 124, no. January, p. 103594, 2021, doi: 10.1016/j.autcon.2021.103594.

[8] L.-Y. Ma and N. Soin, "Recent Progress in Printed Physical Sensing Electronics for Wearable Health-Monitoring Devices: A Review," *IEEE Sens. J.*, vol. 22, no. 5, pp. 3844–3859, 2022, doi: 10.1109/JSEN.2022.3142328.

[9] K. T. Fujimoto *et al.*, "Aerosol jet printed capacitive strain gauge for soft structural materials," *npj Flex. Electron.*, vol. 4, no. 1, p. 32, 2020, doi: 10.1038/s41528-020-00095-4.

[10] J. Navratil, T. Rericha, R. Soukup, and A. Hamacek, "Aerosol Jet Printed Sensor on Fibre for Smart and IoT Applications," in *2018 41st International Spring Seminar on Electronics Technology (ISSE)*, 2018, pp. 1–4, doi: 10.1109/ISSE.2018.8443609.

[11] A. Sanli, R. Ramalingame, and O. Kanoun, "Piezoresistive pressure sensor based on carbon nanotubes/epoxy composite under cyclic loading," in *2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, May 2018, pp. 1–5, doi: 10.1109/I2MTC.2018.8409527.

[12] W. Gao and Q.-M. Wang, "Piezoelectric Pressure Sensors as Switching Devices," in *2021 IEEE International Symposium on Applications of Ferroelectrics (ISAF)*, May 2021, pp. 1–4, doi: 10.1109/ISAF51943.2021.9477348.

[13] M. T. Vijjapu *et al.*, "Printed and Flexible Capacitive Pressure Sensors for Soft Robotics," in *2023 IEEE Applied Sensing Conference (APSCON)*, Jan. 2023, pp. 1–3, doi: 10.1109/APSCON56343.2023.10101193.

[14] T. Watanabe, Y. Kaneko, M. Shimada, and K. Takahashi, "Diaphragm-type miniature optical fiber pressure sensor with a sleeve," in *The 13th International Conference on Solid-State Sensors, Actuators and Microsystems, 2005. Digest of Technical Papers. TRANSDUCERS '05.*, vol. 1, pp. 487–490, doi: 10.1109/SENSOR.2005.1496460.

[15] J. Starke, K. Chatzilygeroudis, A. Billard, and T. Asfour, "On Force Synergies in Human Grasping Behavior," in *2019 IEEE-RAS 19th International Conference on Humanoid Robots (Humanoids)*, 2019, pp. 72–78, doi: 10.1109/Humanoids43949.2019.9035047.

[16] A. Chortos, J. Liu, and Z. Bao, "Pursuing prosthetic electronic skin," *Nat. Mater.*, vol. 15, no. 9, pp. 937–950, Sep. 2016, doi: 10.1038/nmat4671.

[17] D. Thi Ngoc Nga, G. Mattana, V. T. Thu, R. Roussel, and B. Piro, "A simple flexible printed capacitive pressure sensor for chronic wound monitoring," *Sensors Actuators A Phys.*, vol. 338, p. 113490, 2022, doi: https://doi.org/10.1016/j.sna.2022.113490.

[18] M. Amit, R. K. Mishra, Q. Hoang, A. M. Galan, J. Wang, and T. N. Ng, "Point-of-use robotic sensors for simultaneous pressure detection and chemical analysis," *Mater. Horiz.*, vol. 6, no. 3, pp. 604–611, 2019, doi: 10.1039/C8MH01412D.

[19] T. Caporaso, P. Bellitti, S. Grazioso, M. Serpelloni, E. Sardini, and A. Lanotti, "Concept Generation and Preliminary Prototyping of a Tailored Smart Glove with Capacitive Pressure Sensors for Force Grip Analysis in Cycling," *Comput. Aided. Des. Appl.*, vol. 20, pp. 87–98, Dec. 2022, doi: 10.14733/cadaps.2023.S6.87-98.

[20] D. Rempel *et al.*, "The effect of keyboard keyswitch make force on applied force and finger flexor muscle activity.," *Ergonomics*, vol. 40, no. 8, pp. 800–808, Aug. 1997, doi: 10.1080/001401397187793.

[21] M. Corso, A. Abanomy, J. Di Canzio, D. Zurakowski, and S. M. Morgano, "The effect of temperature changes on the dimensional stability of polyvinyl siloxane and polyether impression materials," *J. Prosthet. Dent.*, vol. 79, no. 6, pp. 626–631, 1998, doi: https://doi.org/10.1016/S0022-3913(98)70068-X.

[22] N. Kumari and D. B. Nandeeshwar, "The dimensional accuracy of polyvinyl siloxane impression materials using two different impression techniques: An in vitro study.," *J. Indian Prosthodont. Soc.*, vol. 15, no. 3, pp. 211–217, 2015, doi: 10.4103/0972-4052.158074.

[23] K. Arshak *et al.*, "Novel silicone-based capacitive pressure sensors with high sensitivity for biomedical applications," *e-Polymers*, vol. 4, no. 1, p. 61, Dec. 2004, doi: 10.1515/epoly.2004.4.1.684.