NATIONAL INNOVATION AND RESEARCH ACADEMIA
International Journal of Sustainable Development
ISSN: 2713-4683. Volume 4, Issue 1. Pages 18-30. October, 2025
otl: 2293847487847412
Double Blind Peer Reviewed International Research Journal
https://arcnjournals.com
arcnjournals@gmail.com

Investigation and Testing of Resistive Sensors with Smart Textiles for Wearable Technology: from Production Processes to Integration with Electronics

John Zaitu; Usaini Aliyu & Ibrahim Bala
Department of Fashion Design and Clothing Technology
Hussaini Adamu Federal Polytechnic Kazaure, Jigawa State, Nigeria

Abstract: *This paper examined the fabrication processes, characterization, and integration of resistive sensors within smart textiles for wearable technology applications. Emphasizing the role of conductive fibers and fabric structures, the study reviewed various fabrication techniques, including weaving, knitting, coating, and metallization, to enable electrical conductivity in textiles. Piezoresistive sensors were developed using steel and copper wire configurations and evaluated under different pressure conditions to assess their resistance variations and performance. The results showed that steel wire sensors demonstrated higher initial resistance and better compliance, while copper wire sensors exhibited lower resistance, indicating distinct advantages for different applications. A practical application of the developed sensors was demonstrated through a removable smart insole integrated with read-out electronics and wireless communication to monitor step rate during training. The study highlighted both the potential and challenges of integrating textile-based sensors with electronic systems, particularly in achieving flexible and durable connections. Overall, the findings contribute to advancing smart textile technologies for use in health monitoring, sports, and wearable electronics.*

Keywords: *Wearable Smart Textiles, Piezoresistive Sensors, Smart Watch, Training Shoe, And Log Front End.*

INTRODUCTION

Fabrics are the new silicon wafers; they have generated much interest due to the advent of portable devices and soft computing. Though not a replacement for conventional electronics, this field possesses a market of its own that is still in its development phase, as it does not currently have a standardized set of methodologies or elements. It has become a concomitant development of wearable technologies. This paper includes a review of technologies essential for the development of fabrics with incorporated functionality, with an emphasis on sensor applications. Fabrics which are imbued with sensing properties are called smart fabric sensors (SFSs); these are sensitive to multiple physical and chemical stimuli such as changes in temperature, pressure, force, and electrical current, among others. Sensing elements can be incorporated into fabrics at any level depending on the structural fabric element being modified or sensitized. SFSs are part of the more generalized category of smart fabric transducers (SFTs), which are fabrics that have been treated or modified to act as sensors, actuators and/or other types of transducers. The ubiquitous nature of fabrics makes them an ideal vehicle for the design of sensors that are in direct contact with human beings. These wearable technologies are an active focus of research in diverse fields, including commercial, medicine, military and aerospace, because SFTs provide technological possibilities which are not possible with conventional electronics alone. The intent of this paper is to convey a sense of the breadth of possibilities that fabrics have for being utilized and for either creating new application fields or improving current technologies. It also serves as an initial approach towards standardization of e-textile materials and methods as well as fabric sensing techniques. SFTs provide functionality for measuring or influencing the environment or subject in which they are employed. Three major categories of SFTs are:

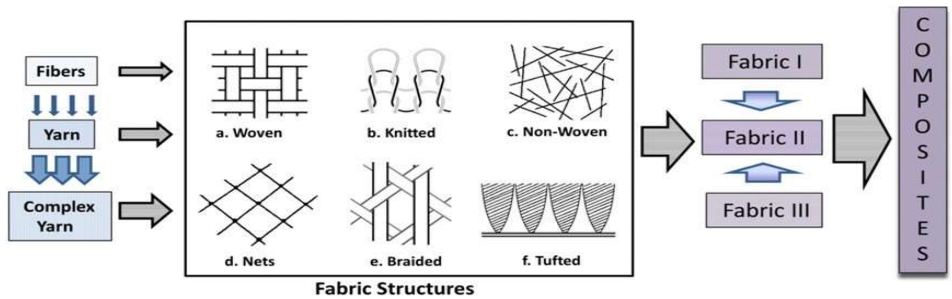


Figure 1. Fabric construction platform and hierarchy. Fabric structures: (a) woven, (b) knitted, (c) non-woven, (d) nets, (e) braided and (f) tufted, which can be assembled in layers (e.g. three layers) to form composite structures.

- Sensors. Fabrics which are given sensing properties of diverse physical nature, such as capacitive, resistive, optical and solar.
- Actuators. Fabrics which are able to actuate or move some aspect of their environment. Examples of these types of fabrics are electroactive fabrics and auxetic fabrics.
- Batteries and energy harvesting. Fabric based batteries and fabrics which use the kinetic energy or the thermal energy of the wearer or their environment to generate electrical power.

There are many additional categories of specialty, high tech, functional and/or advanced material fabrics that will not be examined in this review. Examples of fabrics with functionality that will not be addressed in this review include those which have been modified to address a particular purpose; whether it is to act as a fire retardant (Nomex), have increased strength (Kevlar) or possess luminescent properties. These types of fabrics are beyond the scope of this paper given that they do not possess sensing qualities but rather a very specific property. Other examples/uses of these specialty fab- rics include: heat regulating, EMI shielding fabrics, geotextiles and geosynthetics and specialty fabrics for medicine, transportation and defense.

Several review works have been published which summa- rize the eclectic collection of developments in smart fabrics and intelligent clothing, as well as e-textiles and wearable fabrics. This paper provides a unique review of the different types of fabric sensor and e-textile technologies from the materials and components point of view, as well as the construction procedures and techniques associated with them. The current topic of review was not previously available in the literature.This paper is organized as follows: first, fabric sensors platforms are explained in the context of the broader field of SFT platforms. Second, fabric construction and hierarchy is presented for a general fabric transducer and hence for fabric sensors. Smart sensing functionality is then shown to be a result of intrinsic and extrinsic modifications to the fabric platform. Third, the materials, connection and fabrication methods used in e-textiles are presented in the context of SFSs and the wider field of SFTs.

Textile circuit elements

Textile circuit elements can be miniaturized and encapsulated to be adapted to the fabric structure. Small off-the-shelf components can be sewn into the conductive lines on the fabric either directly or by using holders, sockets or sequins which can be attached to the fabric by different methods. Sequins can be sewn into conductive thread lines while holder leads can be soldered to a fabric FCB, which is a pre-treated solder able fabric. These sewing tabs add a negligible amount of resistance to the circuit. The resistance across a typical fabric tab to stitching joint is less than. Components can then be easily attached to the e-textile, providing a convenient platform for the wiring of textile circuitry. The same techniques can be applied to microcontrollers and other circuit elements. A good complementary implementation of this approach is to use gripper snaps or to staple them in place using pressure—this allows mobility while still in contact, but restrains motion. Fabric switches are another way of connecting the electronic elements and can be made by putting two pieces of conductive fabric together but separated by a piece of felt with a hole in it. When the switch is pressed the two pieces of conductive fabric contact one another through the hole making an electrical connection. Electronic elements can be made out of conductive thread by sewing thread fibers in patterns, possibly with multiple crossings, to achieve desired electrical properties. Conductive properties can be given to thread by several techniques before and after the thread manufacturing process, as depicted in figure 1. Each of these can be tailored to become a circuit element with desired characteristics.

Research Objectives

i. Investigation of Soft sensors and actuators has been developed for interaction with environment, increase of operator's safety, entertainment and physiological parameters monitoring.
ii. Investigation of the fabrication processes for smart textiles with conductive fibers and analyses the applications of soft sensors (pressure, temperature, etc) as components of e-textiles, the fabrication processes of smart fabrics with different type of fibers and discusses the properties of resistance related to smart sensors fabrication with different metal and polymeric fibers. Finally it is reported an example of a smart textile piezoresistive sensor developed for a smart training shoe for step rate monitoring interfaced to a smart watch

MATERIALS AND METHODS

Fabric structure platform influence on SFSs

Fabrics are hierarchically structured fibrous materials. The smaller units, or first level of integration, are called fibers, which are characterized by having a high ratio of length to thickness, these units interlace to form thread. Thread gets twisted to form yarn, considered as the second level of integration. Yarn gets turned into what we call fabric, the third level of integration, using different techniques such as weaving and knitting. Larger scales of hierarchical levels (fourth level and up) entail composite or compound fabric units. Figure 1 shows the general progression of fabric structures; from fiber to cloth. A disambiguation must be made: sometimes thread is defined as yarn; however, yarn is usually thicker than thread and sometimes it can be made directly from the constituent fibers. Textiles are defined as anything made from fibrous materials. This includes fabrics and refers to any material constructed through weaving, knitting or other fabrication techniques. Cloth refers to a fabric used for a specific purpose. In this review the words textiles and fabrics are used interchangeably. The construction of fabrics is crucial when building SFSs and SFTs in general; it will determine the type of bond needed for mechanical attachment to the fabric in the case of externally modified textiles, or the type of constituent element modification required for a more intrinsic integration. Knits are easily deformable while woven are usually stable fabrics and hard to deform. A third category, non-woven, are normally made from filaments or fiber webs and are strengthened by different bonding techniques such as adhesive bonding, mechanical interlocking by needling, fluid jet entanglement, thermal bonding and stitch bonding . Other types of fabric structures are those made by compressing yarns or by creating nets out of them. Woven, knits and some non-woven are set together mechanically, while nets or compressed fabrics usually undergo chemical modifications. Woven are typically constructed using fairly straight interconnections of wefts (transverse threads) and warps (longitudinal threads). Knits are typically made up of looped interconnections of courses and wales, where the wales are the threads that run vertically

Fabrication processes of conductive smart textiles.

Conductive fibers are the key element to build smart fabrics with known electrical properties (resistance, capacitance etc). The current flow in fabrics depends on: conductive material used, % of conductive fibers, fabric structure, and conductive fiber contact surface. The fabrication technologies that use metal fibers only and a mixture with textile fibers are described. These yarns are produced using textile production technologies. Advanced processes of metallization of polyamide fibers with silver coating are also developed because polyamide gives the yarn strength and elasticity, while thin compliant silver coating guarantees electrical conductivity. Carbon fibers can also be used to produce smart fabrics, for the fact that carbon is a conductive material. They are about 0.005–0.010 mm in diameter, produced from a precursor polymer; the precursor is first spun into filaments and after Spinning, the polymer fibers are then heated to drive off non-carbon atoms (carbonization). Thanks to carbon electrical properties very low temperature coefficient of resistivity - 0.0005 [1/°C] are achieved. Electrons flow along different directions in the fabric depending on the thread: in woven fabrics the current flows in the orthogonal directions of the filaments with almost same resistance while in knitted fabrics the resistance offered in the two orthogonal directions is different (see Figure 2). The functionality of these smart fabrics is exploited to build new resistive soft sensors.

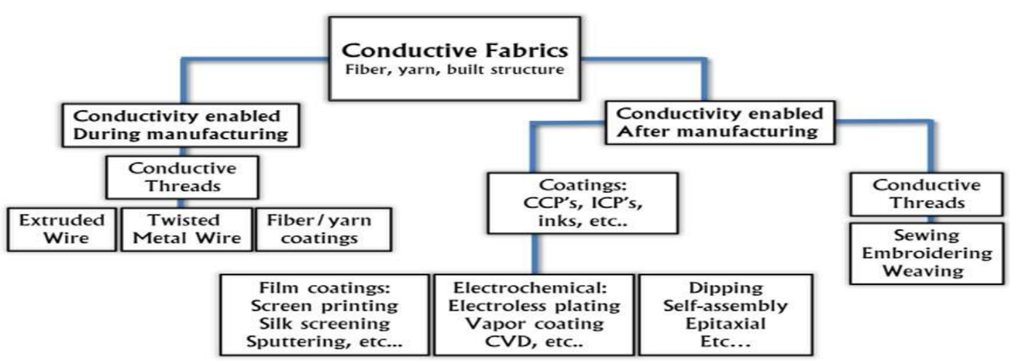


Figure 2. Techniques to enable conductivity in fabrics

Smart fabrics sensors

Fabric sensing concepts have been explored for use in many different capacities and with a huge variety of applications in mind. However, no standard fabric elements or components have been recognized as the most promising candidates for establishing the foundation of the field. Using charts, figures and summary tables, this section will illustrate the more common sensing mechanisms found in fabric sensors.

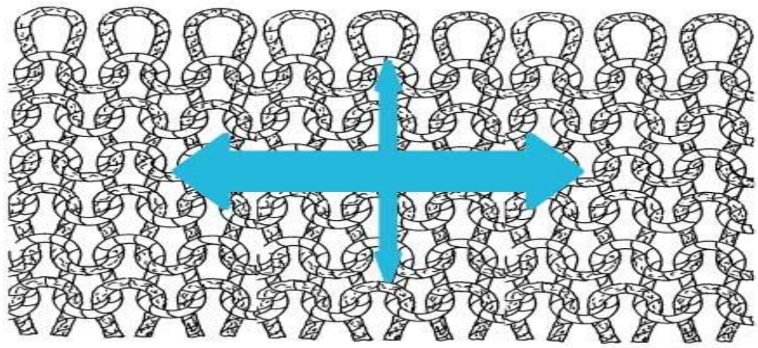
Pressure and force sensors

Capacitive fabric sensors are usually designed for pressure and tactile sensing applications. Many different designs and materials have been tested and prototyped for application to fabrics. They range from adapted electronics to intrinsically modified materials, yet all have in common a dielectric element that separates two electrodes. In adapted electronics, e-textiles employ conventional capacitors that are attached to fabrics using customized methods. Usually, an adapted capacitor will be mounted on a frame which can be sewn, snapped or glued to a fabric substrate and soldered to other electronics or wires. Fabric capacitors can also be constructed from compliant conductive materials acting as electrode plates that are separated by dielectrics and spacers of various origins. The plates can be woven, sewn, and embroidered in the case of conductive thread/fabrics, or they can be painted, printed, sputtered, and screened in the case of conductive inks, polymers and paints. The dielectrics used are typically synthetic foams, fabric spacers, and/or soft polymers. Capacitive fibers can also be manufactured using techniques similar to those found in flexible electronics, such as a silicon fiber sputtered with metals. Fabric sensor capacitors can be used as a single element but they can also be placed in arrays to obtain distributed measurements. In both cases they usually follow the classic capacitor construction. In arrays, capacitance is measured at intersecting rows and columns of electrodes], which are in turn connected to multiplexers and microcontrollers to DAQ systems. Other distinct capacitive sensing mechanisms include switches, tactile contact and those which use the human body capacitance. Table 1 presents examples of the different ways in which capacitive sensors can be made out of compliant materials.

Next, we consider compressible foams, fabrics and polymers. These materials have several drawbacks, including creep, poor resilience, signal drift, and hysteresis. Compensation for these problems depends on the intended usage and the acceptable operating range. Capacitive fabric sensor outputs are typically non-linear, with regions of approximate linearity (table 1). Foams typically have more hysteresis than other 3D fabric spacers, but negligible long term drifting and creep. Humidity and temperature effects have not been fully studied across the range of sensors discussed above. Studies by Meyer *et al* [suggest that there is a change in capacitance between wet and dry spacers, with wet spacers exhibiting an increase in capacitance. Robust insulating methods and compensation need to be developed to account for these issues. Capacitive fabric sensors can be built at many scales, from micro components to large sensing areas (figure 2).

Resistive smart sensors

The resistance provided by a smart fabric is measured with two electrodes of specified configuration that are in contact with the same side of a material under test this relation depends on the type of material and, for non-homogeneous fabrics, even from the orientation of the specimen. Because the lack of standards, manufacturers often adopt their own measurement protocols and provide the value of surface resistance or linear resistance. Because the dependence of resistance from other physical quantity this paper will explore applications of smart textile sensors for textile sensors are able to measure: mechanical pressure, strain, position (potentiometer) and temperature.For each type of smart textile resistive device is important the characterization of the performances with laboratory test under electrical, mechanical and temperature conditions. This paper presents the characterization of a soft electrical switch element that can be arranged also as a matrix of switches. Some of the innovative aspects of the pressure sensitive fabrics used for a soft switch are: no



need of further production steps, low cost, transpiring, semi-transparent, flexible, different act ivating pressures, matrix switches, large area (up to 50 cm x 50 cm) switches (see left picture in Figure 2), skin compatible materials.

Figure 3: Current density and directions: (Left) in a woven fabric, (Right) knitted fabric.

Figure 4: (Left) Pressure sensitive fabrics used as electronic switch. (Right) Piezoresitstive matrix of 8x8 sensors with connectors for column- row readout electronics.

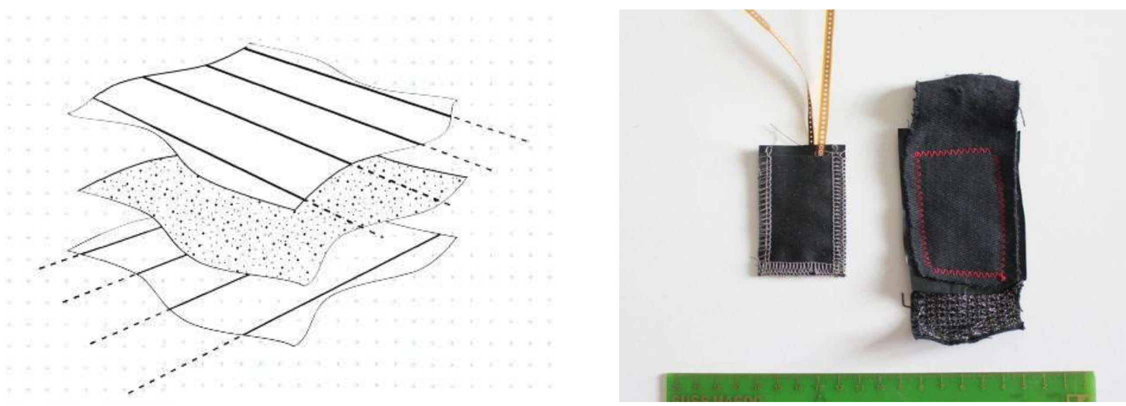


Figure 5: (Left) Structure of a pressure sensitive fabric made of two outer layers with orthogonal conductive patterns and a Velostat (3M^{TM}) intermediate layer. (Right) Two piezoresistive sensors based on knitted fabric process with different metal wires: steel and copper.

RESULTS AND DISCUSSIONS

Piezoresistive sensor characterization

Two types of piezoresistive sensors were fabricated, each with dimensions of 60 mm × 40 mm, corresponding approximately to the active sensing area required for the insole application. The resistance (R) of the sensors was characterized under two conditions: when no pressure was applied (P = 0) and when subjected to a uniform pressure of P = 4583 N/m². The results, summarized in Table 1, provide a clear comparison of the resistance behavior of both sensor types under these conditions.

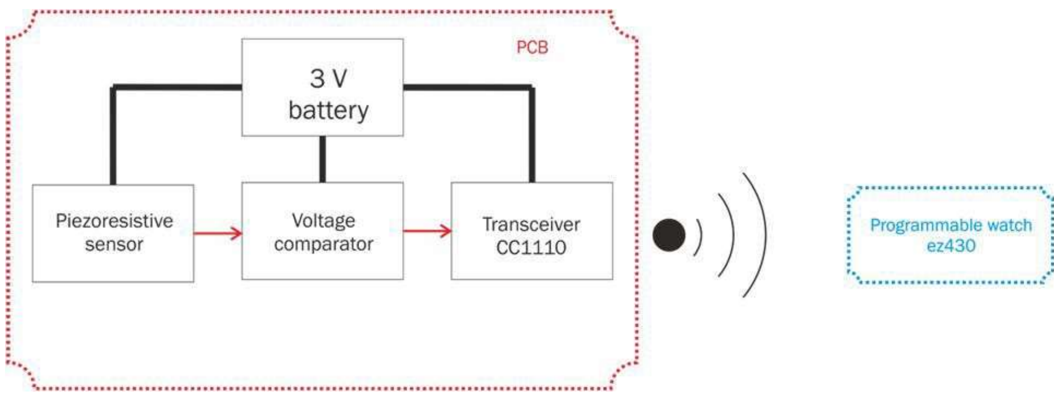
Table 1. Resistance variation with pressure

Type of sensors	P=0	P=4583 N/m^2
Steel wire	R = 38kOhm	R = 3.2kOhm
Copper wire	R = 870 Ohm	R = 140 Ohm

The advantage of a greater resistance of the steel wire is the lower power consumption when the piezoresistive sensors voltage is measured by a voltage divider with a series resistance of 1kOhm and power supply of 3.3V. The steel wire model has the advantage of greater compliance and isotropic current flow being built with a 0,07 mm diameter wire. However, the lower resistance in the rest condition requires an electronic interface with switched mode power supply and synchronous measurement of the output voltage in order to limit the power consumption.

Read-out electronics

Finally, an application of a piezoresistive sensors modeled as a removable insole developed for monitoring the step rate during training is presented. This device can be used as an odometer, to count steps or strides, but the smart insole can also measure foot contact and lift durations, pressures, spent energy, etc. A shaping analog interface creates pulses through a voltage comparator and then is processed by a low power microcontroller (Transceiver CC1110). The latter sends the information to a programmable watch to visualize if the step rate is within the expected range. A block scheme of the system is shown in Figure 4. In our case the smart watch is the Texas Instruments EZ430. A challenging problem for the sensors with smart textiles are the connections between the electronics and the sensors and at present a viable solution



are thin flexible circuit based on Kapton substrate; an example of this type of connections is shown in Figure 3 with two flat connections soldered on the knitted wire mesh.

Figure 6: block scheme of the read-out electronics for the smart insole with piezoresistive sensors

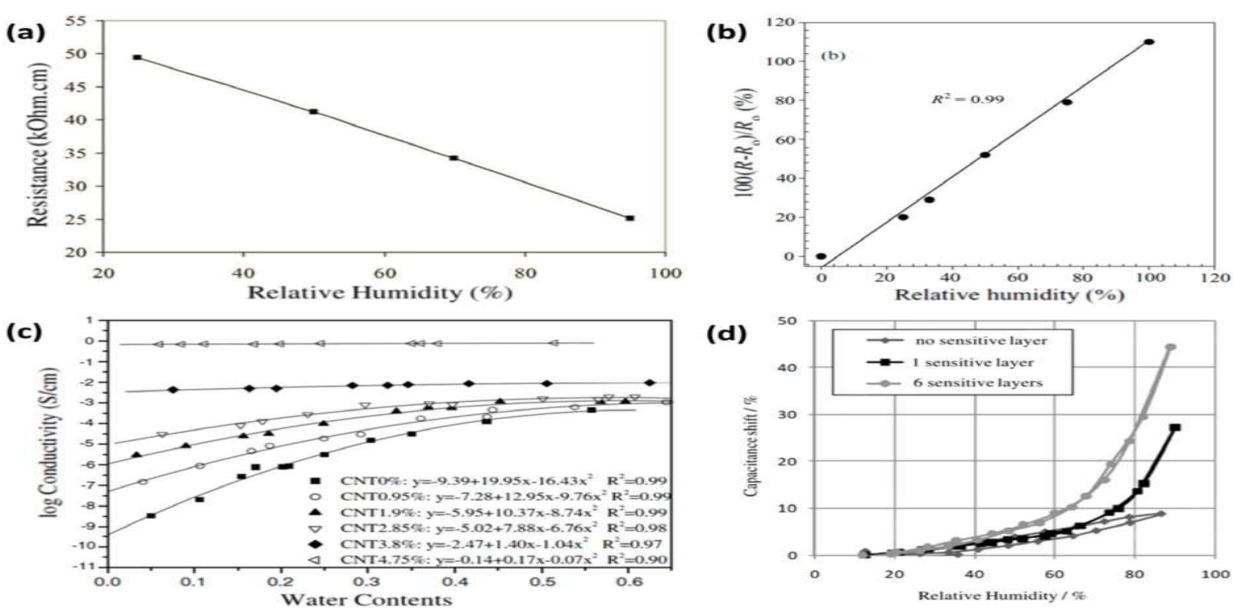


Figure 7. Humidity fabric sensors. (a) Resistance of PEDOT–PSS-coated fibers versus relative humidity during. Reproduced with permission (b) Sensitivity of the PEDOT–PSS/PAN sensor prepared using 9 wt% PAN solution. Reproduced with permission . (c) The effect of water content on the electrical conductivity of GPS with different MWCNT (d) Capacitance shift versus relative humidity for different sensitive polymeric ink layer thicknesses and without sensitive layer (unmodified polyimide substrate).

Carbon nanotube yarn composites can discriminate amine volatile compounds such as ammonium hydroxide, ethanol, pyridine and triethylamine . There are other types of chemical sensing mechanisms such as those which operate with transistor and diode principles. In the transistor case the source–drain current is changed when the sensing film interacts with the analytic. In the diode case, a heterojunction is formed between the polymer and electrode. The barrier of the saturation current density can be modulated by the analytic. Other mechanisms for detecting gases with polymers include optical devices, piezoelectric crystals, and aerometric methods.

Temperature and humidity sensitive fabrics

Multiple humidity sensing mechanisms are possible. Poly- meric based humidity sensors can be divided into two funda- mental categories: resistive type and capacitive type. The first one responds to moisture variation by changing its conductivity while the second one responds to water vapor by varying its dielectric constant. A stainless-steel yarn undergoes a change in resistance when humidity is changed; such a change is possible using fabric humidity collectors which are then in contact with the sensing yarns. Combinations of poly- mer/substrate; PEDOT–PSS/PAN nanofibers,PEDOT– PSS/polyimide, PEDOT–PSS/lycratactel and Polypyr- role] are also responsive to humidity changes by changing their electrical conductivity. These sensitized substrates can later be woven into textiles . Polymers suitable for capacitive humidity sensors include polyethersulfone (PES), poly- sulfonic (PSF) and divinyl siloxane benzocyclobutene (BCB), among others. Other humidity sensing devices entail flexible transistors and changes in spacer fabric dielectrics. Coated sensors on fabrics typically react to humidity if they are organic or carbon based. Water is well known for its protonation and the released proton interacts with universally conjugated C=C double bonds. Examples of humidity sensors found in the literature are shown in figure 4 Almost all of the humidity sensors based on polymers operate at room temperature due to the polymers' high sensitivity to heat.

Temperature sensors which are compatible with fabrics can be fabricated on flexible substrates such as plastics and polyimide sheets. These can be later attached to fabrics or integrated into their structure. Resistance temperature detectors (RTDs) have elements such as platinum and nichrome (NiCr) and related materials that can be coated on flexible surfaces. Kapton based plastic stripes of platinum RTDs can be woven into fabrics to manufacture a temperature sensitive textile. A gold RTD has been manufactured on a flexible polyimide substrate; its resistance changes linearly with temperature. This sensor is also woven into the textile. Thermoelectric generators can also be attached to fabrics using molding techniques and fabric connection

CONCLUSION

The findings of this study highlight the effectiveness of incorporating conductive fibers into textile structures to create functional resistive sensors for wearable applications. The characterization of piezoresistive sensors fabricated with steel and copper wires revealed clear resistance variations under applied pressure, with steel wire sensors demonstrating higher resistance and better compliance, while copper wire sensors exhibited lower resistance suitable for low-power applications. These properties make the sensors adaptable for different functional requirements. The integration of the developed sensors into a removable insole successfully enabled step rate monitoring when connected to read-out electronics and wireless transmission modules, demonstrating their practical utility. Overall, the results confirm that resistive smart textiles can provide accurate sensing capabilities, offering a promising platform for developing advanced wearable systems for sports, health monitoring, and other interactive applications.

REFERENCES

Adanur, S. (1995). *Wellington Sears handbook of industrial textiles*. Technomic Publishing Company.

Arduino. (n.d.). *Arduino LilyPad board*. http://arduino.cc/en/Main/arduinoBoardLilyPad

Axisa, F., Schmitt, P. M., Gehin, C., Delhomme, G., McAdams, E., & Dittmar, A. (2005). Flexible technologies and smart clothing for citizen medicine, home healthcare, and disease prevention. *IEEE Transactions on Information Technology in Biomedicine, 9*(3), 325–336. https://doi.org/10.1109/TITB.2005.854512

Carty, P. (1994). *Fibre properties* (2nd ed.). Formword.

Chen, Y., Lloyd, D. W., & Harlock, S. C. (1995). Mechanical characteristics of coated fabrics. *Journal of the Textile Institute, 86*(4), 690–700. https://doi.org/10.1080/00405009508631279

Cheng, K. B., Ramakrishna, S., & Lee, K. C. (2000). Electromagnetic shielding effectiveness of copper/glass fiber knitted fabric reinforced polypropylene composites. *Composites Part A: Applied Science and Manufacturing, 31*(10), 1039–1045. https://doi.org/10.1016/S1359-835X(00)00065-0

Cherenack, K., & Van Pieterson, L. (2012). Smart textiles: Challenges and opportunities. *Journal of Applied Physics, 112*(9), 091301. https://doi.org/10.1063/1.4742728

Cho, G., Lee, S., & Cho, J. (2009). Review and reappraisal of smart clothing. *International Journal of Human–Computer Interaction, 25*(6), 582–617. https://doi.org/10.1080/10447310902826494

Down, J. (2001). *Textiles technology through diagrams*. Oxford University Press.

Dubrovski, P. D., & Cebasek, P. F. (2005). Analysis of the mechanical properties of woven and nonwoven fabrics as an integral part of compound fabrics. *Fibres & Textiles in Eastern Europe, 13*(5), 50–53.

Edmison, J., Jones, M., Nakad, Z., & Martin, T. (2002). Using piezoelectric materials for wearable electronic textiles. In *Proceedings of the Sixth International Symposium on Wearable Computers (ISWC 2002)* (pp. 41–48).

Farboodmanesh, S., Chen, J., Mead, J. L., White, K. D., Yesilalan, H. E., Laoulache, R., & Warner, S. B. (2005). Effect of coating thickness and penetration on shear behaviour of coated fabrics. *Journal of Elastomers and Plastics, 37*(3), 197–227. https://doi.org/10.1177/0095244305046950

Farringdon, J. (2001). Wearable electronics and clothing from Philips and Levi. *Technical Textiles International, 10*, 22–24.

Gioello, D. A. (1982). *Understanding fabrics: From fiber to finished cloth* (1st ed.). Fairchild.

Hyang, Y., Park, H. K., Lee, Y. M., & Park, S. B. (2007). A practical procedure for producing silver nanocoated fabric and its antibacterial evaluation for biomedical applications. *Chemical Communications, 28*, 2959–2961. https://doi.org/10.1039/b703822h

Liehr, S., Lenke, P., Wendt, M., Krebber, K., Bruns, C., Kühne, M., & Schukar, M. (2008). Distributed strain measurement with polymer optical fibers integrated into multifunctional geotextiles. *Proceedings of SPIE, 7003*, 700302. https://doi.org/10.1117/12.787344

Lomov, S. V., Huysmans, G., Luo, Y., Parnas, R. S., Prodromou, A., Verpoest, I., & Phelan, F. R. (2001). Textile composites: Modeling strategies. *Composites Part A: Applied Science and Manufacturing, 32*(10), 1379–1394. https://doi.org/10.1016/S1359-835X(01)00034-9

McCann, J., & Bryson, D. (2009). *Smart clothes and wearable technology*. Woodhead Publishing.

Meoli, D., & May-Plumlee, T. (2002). Interactive electronic textile development: A review of technologies. *Journal of Textile and Apparel, Technology and Management, 2*(2).

Mondal, S. (2008). Phase change materials for smart textiles—An overview. *Applied Thermal Engineering, 28*(11–12), 1536–1550. https://doi.org/10.1016/j.applthermaleng.2007.08.009

Orth, M. (2002). Defining flexibility and sewability in conductive yarns. In *Materials Research Society Symposium Proceedings* (Vol. 736, pp. 37–48).

Plug and Wear. (n.d.). *Plug and Wear*. http://www.plugandwear.com/

Schwarz, A., Kazani, I., Cuny, L., Hertleer, C., Guxho, G., & Van Langenhove, L. (2011). Electro-conductive and elastic hybrid yarns – The effects of stretching, cyclic straining and washing on their electro-conductive properties. *Materials & Design, 32*, 4247–4256. https://doi.org/10.1016/j.matdes.2011.04.039

Simon, C., Potter, E., McCabe, M., & Baggerman, C. (2010). *Smart fabrics technology development*. NASA Innovation Fund Project, NASA Johnson Space Center Report.

Tao, X. (2001). *Smart fibres, fabrics and clothing*. Woodhead Publishing.

Tracton, A. (2006). *Coatings technology handbook* (3rd ed.). CRC Press.

U.S. Army Natick Soldier Systems Center. (n.d.). Universal Serial Fabric Bus. Retrieved November 18, 2013, from www.natick.army.mil/about/pao/pubs/warrior/02/janfeb/smartclo.htm

Wang, X., Ostblom, M., Johansson, T., & Inganas, O. (2004). PEDOT surface energy pattern controls fluorescent polymer deposition by dewetting. *Thin Solid Films, 449*, 125–132. https://doi.org/10.1016/j.tsf.2003.11.109

Xue, P., Park, K. H., Tao, X. M., Chen, W., & Cheng, X. Y. (2007). Electrically conductive yarns based on PVA/carbon nanotubes. *Composite Structures, 78*(2), 271–277. https://doi.org/10.1016/j.compstruct.2005.09.014