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NATURAL FIBERS IN TEXTILE SENSORS – STATE OF THE ART

N. PALA AVCI[1], Y. KYOSEV[2], O. KYZYMCHUK[2], E.D. KOCAK[1]
[1]Marmara University, Textile Engineering Department, Istanbul, Turkiye
[2]TUD Dresden University of Technology, Germany

This work provides a comprehensive overview of the current state of the art in the integration of natural fibers into textile sensors. As the demand for wearable technology and smart textiles continues to rise, the exploration of sustainable and biocompatible materials becomes imperative. Natural fibers, derived from sources such as cotton, silk, and agricultural waste, offer a promising avenue for the development of textile sensors. The review examines the advantages and challenges associated with the use of natural fibers in sensing applications, considering factors such as comfort, breathability, biocompatibility, and reusability. Furthermore, it explores recent advancements in material science and manufacturing techniques that have contributed to overcoming challenges and enhancing the performance of textile sensors. The article concludes by discussing the potential future directions and applications of natural fiber-based textile sensors in various industries, emphasizing their role in shaping the evolving landscape of wearable and smart textile technologies.

In recent years, there has been a growing interest in the development of textile-based sensors, which combine the functionality of sensors with the comfort and flexibility of textiles. Textile-based sensors, offer unique advantages over traditional solid-state sensors and have the potential to revolutionize the field of sensing. They can be seamlessly integrated into garments, allowing for continuous and unobtrusive monitoring of various physiological and environmental parameters. Wang et al. [1] discussed the theoretical principles of textile-based strain sensors, including resistive, capacitive, and piezoelectric sensors. These sensors can be used for human motion detection and have potential applications in sports performance analysis and healthcare monitoring.

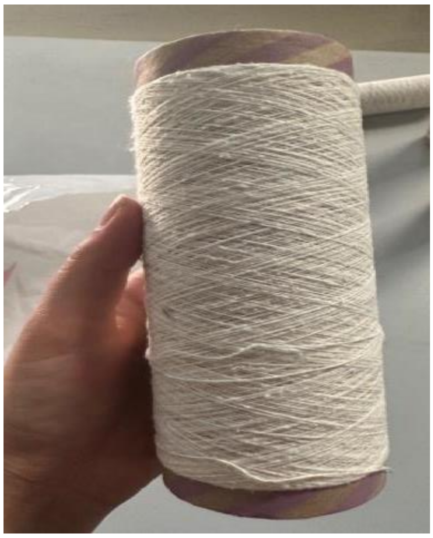
In the past few years, there has been a growing interest in the development of textile-based sensors made from natural fibers. These sensors offer unique advantages such as flexibility, biodegradability, and biocompatibility. One area of research focuses on the use of natural fibers as conductive materials for flexible strain sensors. These fibers can be made conductive through processes like carbonization or compositing with conductive materials [2]. Souri and Bhattacharyya [3] produced conductive threads by coating flax fibers with graphene nanoplatelets and carbon black using novel ultrasonication method. These threads were then used to produce wearable, stretchable and durable strain sensors. In another study, a sensor yarn based on natural sisal yarn impregnated with PVA polymer and coated with PEDOT:PSS polymer as an electroconductive sheath was investigated. The primary aim of the study was explained as the development of the sensor yarns. In the future, it is planned to create textile surfaces with sisal sensor yarns by using different textile technologies and examine the mechanical behavior of these surfaces [4].

Although textile-based sensors have a wide application area and increasing popularity, one of the most important criteria for future e-textiles will be the use of natural materials. For this reason, sustainable materials or production methods have been preferred in many studies conducted in recent years. Ferreira et al. [5] used Ag NPs to coat jute fibers using the Ultraviolet photoreduction method and polyethylene glycol as reductants and stabilizers as two different sustainable methods. Jagadeshvaran et al. [6] also used iron titanate obtained from ilmenite sand, a sustainable and natural resource, together with MWCNTs to coat cotton fabric for EMI protection. In addition to being used in sensor production by coating conductive material, most plant-based fibers, including cotton, jute, banana and bamboo, show high dielectric properties due to the abundance of free hydroxyl groups in their structures that provide polarity. Therefore, they can be used as dielectric layers in capacitive sensors [7].

The hygroscopic and anisotropic properties of natural fibers are thought to be limiting in sensor applications. However, these features have been combined with 3D printing technologies and started to be used in the development of programmable materials. For example, the hygroscopic property of wood fiber enables the structural transformation of composites produced with this fiber in response to environmental changes such as temperature, humidity and light radiation. The integrated anisotropic cell wall structure and 3D printing patterns enable precise control over the directions and degrees of deformation, called curling. In a study by Correa et al. [8], 3D printed wood composites showed programmed curling after exposure to water vapor, in accordance with the planned design of the composites. This curling behavior was found to be completely reversible over 30 cycles with no change in the curling interval.

Nowadays, instead of fibers obtained from traditional sources, natural fibers obtained from agricultural wastes also attract attention. Agricultural waste fibers offer several advantages, including their abundance, low weight, biodegradability, and renewable nature. These fibers can be used as reinforcing materials in polymer composites, providing enhanced mechanical properties to the sensors. For example, rice husk, a byproduct of rice milling, has been explored as a filler material in reinforced polymer composites [9]. The use of agricultural waste fibers not only provides a sustainable solution for waste management but also contributes to the development of eco-friendly sensor materials. Researchers have investigated various agricultural waste fibers for sensor applications. Pineapple leaf fibers (PALF), derived from pineapple leaves, have been processed and used to reinforce natural rubber in sensor development [10]. The incorporation of PALF in natural rubber composites enhances their mechanical properties, making them suitable for sensor applications. Additionally, the repurposing of agricultural waste biomass, such as banana plant residual biomass, has been explored for fiber production [11]. Fibers obtained from agricultural waste are generally added to the matrix structure as a reinforcer in sensor production. However, over time, studies on spinning yarn from these lignocellulosic fibers are increasing. In this way, instead of being used only as reinforcement in composites, fibers obtained from agricultural waste can be spun into yarn (Fig.1) and then turned into textile surfaces with different textile technologies to be used for strain and piezo sensors. These fibers can be used in the fabrication of sensors, contributing to the circular bioeconomy and sustainable utilization of agricultural waste.

a



b

Fig. 1. Novel yarn with recycled PES/Tomato fibers as option for sensor production: a) tomato fiber; b) rPET/tomato yarn

Despite the advancements in textile-based sensors, there are still challenges that need to be addressed. The complex manufacturing processes of textile sensors can limit the creation of free-form sensor designs [12]. Challenges associated with producing textile-based sensors from fibers produced from agricultural waste include the need for conductive fibers with excellent electrical conductivity and stability against external deformation. These challenges encompass the heterogeneous nature of natural fibers, marked by variations in cell wall structure, composition, and geometry, resulting in a broad range of different fiber quality. Additionally, natural fibers exhibit relatively lower mechanical properties, hydrophilicity causing compatibility issues and a tendency to aggregate in hydrophobic polymer matrices, high water absorption, low thermal stability, and complexities in processing into yarns and fabrics compared to glass fibers [13]. Recent progress in process and product innovation, particularly in fiber processing and modification, have made significant strides in addressing some of these challenges. Ongoing enhancements in the performance of sensors made from agrıcultural waste fibers are expected to propel the global demand for these sensors and broaden their applications.

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