



(REVIEW ARTICLE)

A review on recent trends in smart textiles

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Abstract

Recent advancements in both domestic and international research have considerably enhanced the development of smart fibers and smart textile, which are now being increasingly integrated into the textile industry. Advanced textiles encompass five primary functions; sensors, data processing, actuators, storage and communication. These technologies must be effectively integrated into clothing, ensuring they meet essential requirements like comfort, durability, and resilience to routine maintenance. Designers engaged with traditional textiles might address challenges by integrating smart materials and re-evaluating their design methodologies to leverage the distinctive properties of these advanced materials. This review examines recent developments in Smart Textiles, emphasizing the materials and their recent trends.

Keywords: Textile; Smart fibers; Data processing; Sensors; Market review

1. Introduction

The term "Smart Textiles" encompasses a diverse domain of research and innovations aimed at enhancing the functionality and applicability of conventional fabrics. These textiles are characterized by their ability to interact with the environment or user and include fibers, filaments, and yarns, as well as woven, knitted, or non-woven structures.^[1] Meena et al. defined smart textiles as fabrics crafted from advanced or responsive materials capable of detecting stimuli and facilitating information transmission. Consensus among scholars holds that smart textiles possess the ability to sense environmental conditions (sensing function), act upon them (actuating function), and adjust their behavior accordingly (adaptive function), with their complexity progressing through three generational stages.

The first generation, termed passive smart textiles, includes materials that solely detect external stimuli. The second generation, known as active smart textiles, not only senses environmental stimuli but also responds to them. The third generation, referred to as advanced, very smart, or ultra-smart textiles, integrates the capabilities to perceive, respond to, and adapt to environmental changes ^[2].

2. Materials

2.1. Smart fibers

In tandem with advancements in innovative technology and science, the textile industry has experienced significant transformations in recent years. Textiles are no longer merely utilized for warmth, protection, and fashion. Instead, they now offer distinct properties and functionalities that adapt to external environmental changes through the incorporation of smart fibers, unique structures, or cutting-edge fabrication technologies. Unlike traditional fibers,

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smart fibers not only provide added value but have also been modified for applications across diverse fields. These fibers come in two forms: passive smart fibers and interactive smart fibers

2.1.1. Passive smart fibers

Smart fibers are characterized as fibers, yarns, or mats that possess specific functions independent of external stimuli, such as anti-bacterial, self-cleaning, or waterproof-breathable properties. The motivation to engage with the external environment is minimal. Nevertheless, the inherent properties or structures of these fibers, or the integration of functional components, likely endow them with varying degrees of intelligence.

2.1.2. Interactive smart fibers

In contrast to passive smart fibers, interactive smart fibers—classified as a type of functional material—exhibit autonomous interactive behaviors tailored to specific requirements. These behaviors typically involve receiving information or stimuli and providing feedback. Interactive smart fibers possess the capability to adapt in response to external environmental signals, demonstrating a higher degree of responsiveness^[4].

2.2. Smart textile

Smart textiles are advanced materials and structures that incorporate active control mechanisms to sense and respond to environmental stimuli. These textiles can exhibit substantial alterations in their mechanical properties—such as shape, colour, and stiffness—or in their thermal, optical, or electromagnetic characteristics, depending on the stimuli encountered. They integrate a variety of components, including sensors, actuators, and electronic devices, to function as complex systems. ^[5] Indeed, there is no universally accepted classification for smart textiles; they are typically categorized based on their functionality into three types:

2.2.1. First generation: passive smart textiles

Passive smart textiles are designed solely to detect and report information regarding environmental conditions or stimuli. These textiles are equipped only with sensors. Examples include ultraviolet-protective clothing, plasma-treated garments, and fabrics embedded with optical sensors.

2.2.2. Second generation: active smart textiles

The second generation, or active smart textiles, incorporates both sensors and actuators. These textiles can remember their shape and structure, exhibit color-changing properties, regulate temperature, repel water, absorb vapors, and heat up as needed. They represent a more sophisticated form of "smart" fabric.

2.2.3. Third generation: ultra-smart textiles

The third generation, known as ultra-smart textiles, represents a significant advancement. These textiles can not only monitor various data types but also predict and adapt to external conditions without manual adjustments. Equipped with an integrated microcomputer, they function similarly to a brain. Examples include spacesuits, I-wear, sport jackets, musical jackets, and wearable computers^[3].

2.3. Functions of smart textiles

Essentially, an intelligent suit can be characterized by five distinct functions: Sensors, Data Processing, Actuators, Storage, and Communication. Each function serves a specific purpose, though not every intelligent suit will encompass all these functions. The functions may be overt or inherently integrated into the material or design. Each function demands suitable materials and construction, ensuring compatibility with the suit's fundamental requirements: comfort, durability, and resistance to standard textile maintenance practices.

2.3.1. Sensors

The fundamental principle of a sensor is its ability to convert one type of signal into another that can be interpreted by a designated reader, whether that reader is a physical device or a human. In the case of physical devices, signals are predominantly converted into electrical forms. Textile materials, due to their extensive coverage of the body, serve as highly effective measurement tools. The bio-signals commonly referenced in the literature include: temperature; biopotentials such as cardiograms and myograms; acoustic signals from the heart, lungs, digestion, and joints; ultrasound for blood flow; motion related to respiration; humidity from sweat; and pressure related to blood. It is

important to note that this list is not exhaustive. Significant research is required to identify the optimal parameters for measuring specific bodily functions and to develop suitable algorithms for data interpretation.

Currently, suits are available that can measure heart rate, respiration rate, temperature, motion, and humidity. These typically incorporate conventional sensors embedded within the fabric. However, there are emerging examples of textile sensors for monitoring heart rate, respiration, and motion that have already demonstrated promising results.

2.3.2. Data processing

Advanced data processing is essential only when active processing is required. Currently, the primary challenge lies in the interpretation of data. Textile sensors have the potential to generate vast amounts of data, but the interpretation of this data is problematic due to several issues: significant signal variability between patients, the complex nature of analyzing both stationary and time-dependent signals, the absence of objective standard values, and the lack of understanding of the intricate interrelationships between parameters. Furthermore, the textile material itself lacks computing power, necessitating the use of electronic components. While these components are available in miniaturized and flexible forms and can be embedded in waterproof materials, their durability remains limited. Ongoing research aims to integrate active components into fibers, yet several practical challenges must be addressed before computing fibers become commercially viable, including resistance to washing, deformation, and establishing reliable interconnections.

2.3.3. Actuators

Actuators react to stimuli generated by sensor functions, potentially following data processing. They enable movement, release substances, produce sound, and perform various other actions. Among the most well-known examples in this domain are shape memory materials, particularly shape memory alloys, which are available in filament form. Due to their responsiveness to temperature changes, shape memory materials are suitable for use as actuators and align well with the demands of smart textiles. To date, applications of shape memory alloys in textiles have been limited. Notably, the Italian company CorpoNove, in collaboration with d'Appolonia, has developed the Oriccalco Smart Shirt.

2.3.4. Storage

Smart suits frequently require substantial storage capacity. The storage of data or energy is paramount, with sensing, data processing, actuation, and communication all demanding energy, predominantly electrical power. Efficient energy management entails an optimal integration of energy supply and storage capabilities. Potential energy sources available to a garment include body heat (Infineon [8]), mechanical motion (such as elastic deformation of the fabrics or kinetic energy from body movement), and radiation (particularly solar energy).

2.3.5. Communication

In the realm of intelligent textiles, communication manifests in various forms: it may be necessary within a single component of the garment, between the components themselves, or between the wearer and the garment to transmit commands or information, and vice versa. Currently, communication within the garment is facilitated either through optical fibers or conductive yarns. For instance, to develop a flexible textile display, the employment of optical fibers is particularly advantageous. France Telecom has successfully created prototypes, such as a sweater and a backpack, demonstrating these technologies^[5].

2.4. Application of smart textiles

Gore-tex smart fabric ,jacket, wearable motherboard, smart running shoes, biosensor underwear, smart bar, motion detecting pants, NASA aero gel jacket, the sensory baby vest, intelligent garment for fire fighters, fashion^[7].

2.5. Recent trends in smart textiles

Recent technological advancements are outlined to demonstrate the potential of emerging enabling technologies in surmounting existing technological barriers. Additionally, innovative strategies for drug delivery systems, emphasizing the development of functional materials, are detailed to highlight groundbreaking topics poised to influence the future of textiles.

2.5.1. Wearable sensors

Numerous wearable technologies have emerged through the integration of sensors and data-transmitting devices into textiles. This advanced category of wearable electronic systems is engineered to cater to innovative applications across

various consumer sectors, including fitness and healthcare, military, public safety, and sports. Unlike conventional bulky electronic devices, which are typically rigid, smart textiles represent a fiber-based, flexible system capable of enduring complex and severe deformations with remarkable stability.

2.5.2. Drug release systems

Textiles serve as a crucial interface between the human body and its environment, covering most of the body's surface for the majority of the day. This fundamental observation implies that textiles could be utilized as comfortable systems for the delivery of active compounds or pharmaceuticals, either to the body or to the surrounding environment. The skin, which can span up to 2 square meters, presents a potential pathway for drug delivery^[6].

2.6. Market overview

According to a US report by Venture Development Corporation, the smart textiles market was valued at \$248 million in 2004 and \$304 million in 2005, with expectations to reach \$642 million by 2008, reflecting a 27% compound annual growth rate. By 2012, the market had surpassed \$2.5 billion and was projected to exceed \$8 billion by 2018, growing at a 17.7% CAGR. Wrist-wear led the market in 2012, with revenues from wristwatches and wristbands exceeding \$850 million. Consumer applications held the largest market share, surpassing \$2 billion, while enterprise and industrial applications are expected to grow the fastest. North America, particularly the U.S., remains the largest market, but the Asia-Pacific region, led by China, is forecasted to grow the most rapidly. Developing countries could see significant profits from smart textiles but will need increased research, funding, and technology to capitalize on this opportunity.

2.6.1. Market segmentation

This industry is categorized according to the following application sectors: Consumer Products; Military and Homeland Defense/Public Safety Applications; Computing; Biomedical; Vehicle Safety and Comfort; and Others, including Logistics and Supply Chain Management, as well as Signage. Key geographic regions encompass North America, Asia-Pacific, Europe, and the Rest of the World.

2.6.2. Major PLAYERS

Among the principal entities exerting significant influence in this sector are E. I. Du Pont De Nemours and Company, Intelligent Clothing Ltd., Interactive Wear AG, International Fashion Machines Inc., Kimberly-Clark Health Care, Milliken & Company, Noble Biomaterials Inc., Outlast Technologies Inc., QinetiQ North America, Royal Philips Electronics N.V., Toray Industries Inc., among others^[3].

3. Discussion

Recent advancements in textile technologies, innovative materials, nanotechnology, and miniaturized electronics are enhancing the feasibility of wearable systems. However, the crucial determinant for user acceptance of these devices remains fit comfort. We assert that achieving this objective necessitates a focus on the mechanical resistance and durability of materials within the challenging environment presented by the human body and society.

Moreover, we believe that the development of smart textiles demands a multidisciplinary approach, integrating expertise in circuit design, smart materials, microelectronics, and chemistry with a comprehensive understanding of textile manufacturing.

4. Conclusion

Smart fibers and smart textiles, along with their diverse applications, represent significant research focal points in the contemporary textile and apparel industry, as well as pivotal trends for future development. These innovative textile materials serve as the foundation for high-tech functional textiles, enhancing quality of life, increasing product value, improving labor conditions, and addressing industrial needs. Their presence in the application market is poised to expand significantly. As a critical economic growth driver for the textile sector, this emerging industry remains in a developmental phase. However, with ongoing advancements in science and technology, alongside the dedication of researchers, smart fibers and textiles are set to profoundly transform our lives, ushering in remarkable changes.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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