The application of smart fibers and smart textiles

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Abstract. In recent years, domestic and foreign research on smart fibers and smart textiles has achieved many results, and has been increasingly widely used in the textile field. This article introduces the functions of smart fibers and the main seven types of smart fibers, as well as a brief description of shape memory textiles, color-changing textiles, smart temperature control textiles, waterproof and moisture-permeable textiles, self-cleaning textiles, and electronic information smart textiles. At present, smart fibers and smart textiles are mainly used in the fields of medical health care, military protection, entertainment sports, and clothing consumption. At the same time, their prospects and markets are pointed out. Smart fibers and smart textiles have unlimited development potential and prospects.

1. Introduction

From the concept of smart materials proposed by Dr. Craig Rogers of the University of Virginia in the United States, to 1989, Japanese scholar Toshiyoshi Takagi integrated information science into the composition and function of materials and interpreted smart materials, and then smart materials began to develop as new materials in the 1980s. Nowadays, smart materials in fiber form are in a stage of rapid development [1]. In recent years, the knowledge of different disciplines has continuously crossed and merged. The development of advanced science and technology such as electronic information technology, nanotechnology, and microencapsulation technology has made advanced technologies widely used in smart fibers, and the research and development of fibrous smart materials have achieved results. At present, smart fibers and smart textiles show great development potential.

2. Smart fiber

2.1. Smart fiber function

Smart fiber refers to the fiber that has the ability to perceive, respond, and discover functions to the external environment and internal state through the processing of smart materials [2]. The intelligent fiber system has the vital characteristics and intelligent functions such as sensing function, feedback function, information recognition and accumulation function, response function, self-diagnosis function, self-repairing ability and self-adjusting ability. The sensing function means that the smart fiber can sense the external and internal environment, and can detect and recognize external stimuli, such as light, heat, stress, nuclear radiation, and changes in magnetic intensity [3].

2.2. Smart fiber classification
2.2.1. **Shape memory fiber.** The smart fiber that appeared earlier is the shape memory fiber. Shape memory fiber refers to a fiber with a shape memory effect. When the deformed fiber is given certain external stimulus conditions such as pressure and temperature, the shape memory fiber can return to its original shape. Shape memory fibers mainly include: shape memory alloys, shape memory hydrogels, and shape memory polymers. Due to the characteristics of high recoverable strain, low density, easy processing and low cost, shape memory polymers have advantages over shape memory alloys [4]. Nowadays, people pay more and more attention to the development of shape memory fibers.

2.2.2. **Photochromic fiber.** In most cases, photosensitive color-changing substances are organic compounds containing isomers, which can undergo reversible configuration changes under the action of light, and thus exhibit the reversibility of color development or fading [5]. The discoloration mechanism is: under the irradiation of ultraviolet light or visible light, certain compounds will undergo changes in molecular structure or electronic energy levels to form new compounds with different absorption spectra, and under another light condition, this compound will return to its original state, so that reversible changes occur in a continuous cycle [6].

2.2.3. **Photochromic fiber.** Optical fiber is a kind of optical composite fiber that can enclose light energy in the fiber and transmit it in a waveguide mode. It is also called smart fiber and has excellent transmission performance. It consists of two parts: a core and a cladding. There are currently two types of fiber structures that can form a waveguide transmission, namely, step type and gradient type [7]. Because optical fiber has the dual functions of information perception and information transmission, it is widely used as a sensing material. At present, its application technology in optical fiber sensors is very mature.

2.2.4. **Temperature sensitive fiber.** Temperature-sensitive fiber refers to the fiber whose properties will change reversibly with temperature. Extensive researches include heat preservation and moisturizing fiber and temperature-sensitive discoloration fiber. The "Ventcool" fiber developed by Mitsubishi Rayon Fiber Corporation, is called dynamic fiber, which can stretch instantly when the humidity is high, and quickly crimp when dry, corresponding to the environment and dynamic changes [8].

2.2.5. **Conductive fiber.** Conductive fiber refers to a fiber with a specific resistance of less than 1*10^7 Ω•cm under standard conditions (20°C, relative humidity 65%) [9], which has excellent electrical conductivity and can be eliminated by electronic conduction and corona discharge static electricity is currently mainly used to eliminate static electricity, absorb electromagnetic waves, and detect and transmit electrical signals. Conductive fibers can be roughly divided into electron conductive fibers, ion conductive fibers and inductive fibers.

2.2.6. **pH-responsive gel fiber.** pH-responsive gel fibers refer to gel fibers that change in volume or shape with changes in pH. This change is based on stimulus responsiveness at the molecular level, macromolecular level, and intermolecular level. At present, the research on pH-responsive gel fiber has made great progress in some developed countries.

2.2.7. **Healthy smart fiber.** With the enhancement of people's awareness of safety protection, a smart fiber for the purpose of maintaining human health is being continuously developed, such as antibacterial, deodorant, antibacterial, deodorant fiber, and impact resistant fiber. Among them, selective antibacterial fibers are the most widely used. Selective antibacterial fiber refers to a smart fiber that has the ability to inhibit or kill surface bacteria by adding a certain antibacterial substance (antibacterial agent). This fiber can maintain the growth and reproduction of certain microorganisms on the skin surface at a normal level. At present, its preparation methods mainly include finishing method and fiber modification method. The antibacterial agents can be divided into three categories: organic antibacterial agents, inorganic antibacterial agents and composite antibacterial agents [10].
"smart polyamide fiber" developed by US company Nylstar makes the fiber have longer antibacterial effect and safer at the same time by wrapping antibacterial agent inside the fiber.

3. Smart textile
Smart textiles refer to textiles obtained through spinning and weaving using smart fibers as raw materials, or smart textiles obtained by combining other smart materials with textiles [11].

3.1. Shape memory textiles
Shape memory textile is a kind of material with shape memory function introduced into textile through weaving or finishing. Under external conditions such as temperature, mechanical force, light, pH value, etc., textiles with excellent properties such as shape memory, high deformation recovery, good shock resistance and adaptability. The Italian company Corpo Nove designed a "lazy shirt". When the outside temperature is high, the sleeves of the shirt will automatically roll from the wrist to the elbow within a few seconds; when the temperature drops, the sleeves can automatically recover and can also be automatically ironed [12]. Shape memory fabrics can be developed into fashions, protective clothing and accessories with different functions, as shown in Figure 1. With the in-depth research on shape memory materials and the further improvement of textile processing technology, shape memory functional textiles will be further developed.

![Figure 1. British designer Hussein Chalayan uses shape memory fibers to create fashion](image)

3.2. Color-changing textiles
Color-changing textiles refer to textiles that can display different colors with changes in external environmental conditions, such as light, temperature, pressure, etc. With its unique properties, color-changing textiles are widely used in various fields. Civilian can be used to make fashionable color-changing clothing and ever-changing decorative fabrics, military camouflage can be used in military, anti-counterfeiting field can be used as anti-counterfeiting materials, widely used in bills, certificates and trademarks. Color-changing textiles can be obtained by the following three methods: adding color-changing fibers to the fabric; dyeing with color-changing dyes; printing with color-changing paint. Among the three methods, the research and development of color-changing fiber technology is a bit later, but its advantages are the most prominent. The fabric made of it has good hand feel, good washing resistance, and long-lasting discoloration effect.

3.3. Smart temperature control textiles
Smart temperature control textiles mainly include three types of thermal insulation textiles, cool textiles and automatic temperature control textiles. For thermal insulation textiles, the thermal insulation materials developed at home and abroad are mainly solar thermal storage fibers and far-infrared fibers. The solar thermal storage thermal insulation fibers are used to achieve thermal insulation. The principle is that the fibers absorb visible light and infrared rays from sunlight, and then heat radiation to the human body, and finally achieve the effect of heat preservation. Compared with sunlight thermal storage fiber, far infrared fiber has better thermal insulation performance. The reason is that it absorbs the heat emitted by the human body and radiates a certain wavelength of far infrared rays to the human body to reduce the loss of heat by promoting blood circulation, thereby achieving
the purpose of heat preservation. The cooling materials of cool textiles are ultraviolet and heat shielding fabrics, cool fabrics and heat-dissipating fabrics. Among them, the ultraviolet and heat shielding fabrics are mixed with fine ceramic powder in the fiber to give full play to the advantages of ultraviolet reflection function, which can make people feel cool. Cool fabrics generally add metal oxides to polyester fabrics, and use metal oxides to reduce the possibility of clothing fading due to ultraviolet rays and light, and to ensure that the interior of the clothing is cool [13].

People who work in extremely cold environments (such as traffic police in winter) need clothes to warm them and display safety signals at the same time, which is very meaningful to them. Based on such requirements, there is a great need to develop smart textiles that integrate thermal regulation and light-emitting functions, and use coaxial electrospinning to realize light-emitting temperature-regulated smart textiles [14].

3.4. Waterproof and moisture-permeable textiles
Waterproof and moisture-permeable textiles are also called "breathable fabrics", which are functional fabrics that integrate water-proof, moisture-permeable, windproof and warmth retention performance. This kind of fabric can not only meet the wearing needs of people during activities in harsh environments such as severe cold, rain, snow, and windy weather, but also meet the requirements of people's daily life for raincoats, etc., and has broad development prospects. It mainly includes waterproof and moisture-permeable high-density fabrics, microporous membranes, non-porous membranes and intelligent waterproof and moisture-permeable fabrics [15]. The principle of waterproof and moisture-permeable high-density fabric is that gas molecules diffuse from high concentration to low concentration through the gaps between yarns. Microporous membrane waterproof and moisture-permeable fabrics mainly use the difference between raindrop diameter and water vapor molecular diameter to achieve the goal of waterproof and moisture-permeable. The non-porous membrane waterproof and moisture-permeable fabric uses molecular hydrophilic characteristics to increase the tension of the waterproof membrane surface to achieve the purpose of waterproofing [13].

3.5. Self-cleaning textiles
The trend of manufacturing self-cleaning coatings is growing, which can remove inorganic and organic pollutants through two different mechanisms: rolling water droplets; photocatalysis [16]. Rolling water droplets refer to the lotus-shaped or cauliflower-shaped surface, coupled with low surface energy, will form dirty particles on the surface of the fabric, causing the water droplets to roll off and absorb dust, soil, inorganic and organic pollutants, as shown in Figure 2a. In this case, a contact angle value greater than 150° is required. Photocatalysis is the decomposition of organic dirt by light, which can be easily removed during washing, as shown in Figure 2b and c [16].

Figure 2. (a) The mechanism of rolling water droplets to absorb surface contaminants and the naturally rough surface; (b) The mechanism of light decomposition of dirt; (c) The mechanism
of removing dirt from the surface by washing.

3.6. Electronic information smart textiles
Sensatex of the United States designed and developed a smart positioning garment by installing a GPS receiver on the collar. The European Hewlett Packard laboratory has developed a positioning system smart clothing equipped with a personal area network, a global positioning system, an electronic compass and a speed monitor, which is centrally controlled by a remote control device placed on a small display on the sleeve. Children or Alzheimer's patients who wear this kind of clothing can be easily found when they accidentally get lost. Lap-land University and Finnish Reima Tutta and other institutions have developed a ski suit that uses integrated sensors including accelerometer, compass and global positioning system. If the wearer has an accident, this ski suit will be remote the monitoring terminal sends information including the current position coordinates and physiological measurement data for timely rescue [17].

The smart emotion-sensing clothing is designed and developed by two groups of researchers from the University of Montreal and the University of London. The windbreaker is equipped with a loudspeaker, sensors and a body signal analyzer, which can monitor the user's body signal to determine the user's emotional changes. When feeling down, the windbreaker will play some light music to soothe the mood. This kind of clothing can help autistic patients to get out of confinement, and it can also help the elderly living alone to establish communication with their families [18]. At present, emotion-aware clothing is still in the testing stage, and more practical products are still being designed and developed.

4. The application status and prospects of smart fibers and smart textiles
In the current period, the application of smart fibers and smart textiles is becoming more and more mature, and consumer acceptance is increasing. At present, the main application fields of smart fibers and smart textiles are: medical health care, military protection, entertainment and sports, and clothing consumption. Especially in the fields of medical health care, entertainment and sports, consumers in developed countries are paying more and more attention to their own physical and mental health. The emergence of smart textiles satisfies these needs well, and most of the R&D and production locations are Developed countries, correspondingly, our country still has a certain gap compared with developed countries such as Europe, America and Japan. This gap is mainly due to the early development of multidisciplinary cross-border integration in Europe and the United States and the successful transformation and upgrading of the textile industry. Our country has entered the research time in this field is relatively late, and the textile industry pays too much attention to clothing, household fields and insufficient consumer markets. At the same time, there are many applications of smart fibers and the combination of fabrics and electronic components in the production and development of smart textiles. Most smart textiles not only have the functionality of textiles, but also have the intelligence to react to the external environment and automatically adjust. Enter the age of intelligence in the true sense [19].

Wearable technology is indispensable in the production of smart textiles, and these technologies will also help the textile industry and wearable devices to develop vertical markets. People can use these smart textiles to monitor their health and ensure the quality of life. China predicts that the elderly population over 60 will reach 400 million around 2040, and the elderly population will reach its peak in 2050. The emergence of smart textiles and clothing and related technologies is an effective way to realize the integration of hospitals, communities, families and individuals, and an effective way to alleviate people's demand for health monitoring and limited medical resources. At present, wearable health monitoring systems have become one of the emerging frontier research fields that have attracted much attention in the world, and the domestic market has great potential. In recent years, China has been unremittingly committed to the research and development and design of smart clothing, following the user-centered design concept, combining wearable technology and electronic
information technology, it has developed smart textile and apparel products that can be used in the fields of health care, functional protection, sports and leisure. According to the prediction of the University of Cambridge, the market for wearable products using smart textiles will reach 70 billion U.S. dollars in 2022, and will develop in the direction of lightweight, fashionable, personalized, low-cost and with communication functions [20]. In the future, smart fibers and smart textiles will present three trends: performance optimization, green safety, and industrialization.

5. Conclusion
Smart fibers and smart textiles and their applications are research hotspots in today's textile and apparel field, as well as future development trends. Smart textile materials are the cornerstone of high-tech functional textiles. It can improve the quality of life, increase the added value of products, improve labor conditions, and meet the needs of the industry, and it will inevitably appear more in the application market in the future. It is an important economic growth point for the textile industry in the future, but it is still an emerging industry and not yet fully mature. With the advancement of science and technology and the efforts of scientific and technological workers, smart fibers and smart textiles will bring more convenience to our lives and bring about earth-shaking changes in people's lives.

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References
[1] Huang M and Chu J 2018 J. Tianjin Textile Technology 6 43-6
[2] Yang L 2017 J. China High-tech Zone 5 60-1
[3] Hao X and Yang Y 2010 China Textile Publishing House
[4] OH S, OH K, DAO T, et al. 2012 SCI 62 54-62 DOI:10.1002/pi.4366
[5] Fan F, Wu Y 2017 Journal of Applied Polymer Science 134 44698
[6] Shen L and Fang D 2015 J. Cotton Textile Technology 43 76-9
[7] Gu C 2008 J. Chemical Abstracts 1 22-4,28
[8] Yang Y and Li Q 2006 J. Textile Technology Progress 3 17-8,22
[9] Ding C, Cheng B, Ren Y, Kang W and Zhang J 2006 J. Textile Science Research 3 32-9,25
[10] Li Y, Shi H, Tan Y and Zhu P 2012 J. China Chemical Fiber 11 80-3
[11] Zhou P 2016 J. Shandong Textile Economy 5 28-30
[12] Liu S and Wang L 2013 J. Chemical fiber and textile technology 42 27-9,35
[13] Zhang Y 2017 J. Dyeing and finishing technology 39 6-9
[14] Lu Y, Xiao X, Liu Y, Wang J, Qi S, Huan C, Liu H, Zhu Y and Xu G 2019 J. Alloys and Compounds 812
[15] Su Y, Ye L, Liu B and Wu A 2016 J. Dyeing auxiliary 1 23-7
[16] Gugliuzza A, Drioli E. 2013 J. Journal of Membrane Science 446 350-75
[17] Wu Y and Liu Q 2018 J. Cotton Textile Technology 46 79-84
[18] Fan Y, Hu K, Tao R, Li Q, Zhang F and Huang H 2017 J. Dyeing and finishing technology 39 1-6
[19] Sun J, Li W and Shen J 2019 J. China Fiber Inspection 6 125-7
[20] Luo Y 2019 J. Textile Herald 7 61-2,64-6