

ISSN 2181-8622

Manufacturing technology problems



Scientific and Technical Journal Namangan Institute of Engineering and Technology

INDEX  COPERNICUS
INTERNATIONAL

**Volume 10
Issue 3
2025**



ENERGY-INTEGRATED SMART TEXTILES: INTERNATIONAL TRENDS AND PROSPECTS FOR UZBEKISTAN'S RESEARCH ECOSYSTEM

SHODMONOV JASUR

PhD, Namangan State Technical University, Namangan, Uzbekistan

Phone.: (0593) 672-2288, E-mail.: phd.shodmonov@gmail.com

Abstract: Smart textiles—also known as electronic textiles (e-textiles)—represent a rapidly growing field in which flexible fabrics are embedded with electronic components to provide advanced functionality such as real-time sensing, data processing, and wireless communication. This study presents a modular analysis of smart textile systems by exploring five core components: sensors, microcontrollers, actuators, communication interfaces, and energy storage units. Emphasis is placed on energy autonomy through the integration of gel polymer electrolyte (GPE)-based supercapacitors, thermoelectric generators (TEGs), and piezoelectric yarns. International case studies from institutions such as MIT, KAIST, and the Chinese Academy of Sciences are used to benchmark global progress. The interdisciplinary convergence of materials science, electronics, and textile engineering is highlighted as a key enabler of innovation. The paper concludes with practical recommendations aimed at advancing national research infrastructure and accelerating the commercialization of smart wearable systems.

Keywords: Smart textiles, wearable electronics, flexible sensors, microcontrollers, GPE-supercapacitors, piezoelectric yarns, biosensor fabrics, energy harvesting, self-healing materials, textile integration, mechatronics, modular design.

Introduction. Smart textiles, also referred to as e-textiles or wearable electronics, are a rapidly emerging domain at the intersection of textile engineering, materials science, and digital technology. Unlike traditional textiles that serve mainly thermal insulation or aesthetic functions, smart textiles integrate miniaturized electronics—such as sensors, microcontrollers, actuators, wireless modules, and energy systems—directly into the fabric. These components enable real-time sensing, data processing, and feedback response through seamless contact with the human body, turning fabrics into cyber-physical systems capable of advanced interaction and monitoring functions.

The concept of smart textiles was first introduced in the early 1990s by researchers at the Massachusetts Institute of Technology (MIT) Media Lab, where initial prototypes were developed to monitor body temperature, heart rate, and motion parameters in real time, laying the groundwork for wearable sensing technologies as noted by MIT Media Lab researchers [1].

Subsequent advancements in the field were systematically reviewed by Stoppa and Chiolerio [2], who classified smart textile systems into two primary categories: (1) passive systems that merely sense data, and (2) active systems that not only sense but also process and respond to data dynamically. This classification underscores the technological progression toward more autonomous and intelligent fabric systems.

In a similar vein, Castano and Flatau [3] emphasized that the development of smart textiles represents an interdisciplinary convergence—bringing together electronics, information technology, medical engineering, and materials science to create highly functional and responsive textile platforms.

The practical significance of smart textiles is becoming increasingly evident in diverse fields such as health monitoring, physical rehabilitation, sports performance

optimization, military operations, and industrial safety. According to IDTechEx projections, the global market for wearable technologies is expected to surpass \$100 billion by 2028 [4], further amplifying the demand for smart clothing that is not only flexible and washable but also energy-autonomous.

To meet these growing requirements, leading international institutions—including MIT, KAIST, ETH Zurich, and the Chinese Academy of Sciences—are investing heavily in cutting-edge solutions such as flexible gel polymer electrolytes (GPEs), thermoelectric generators (TEGs), and self-healing ion gels aimed at enhancing the energy efficiency, durability, and functionality of next-generation wearable systems [5–8].

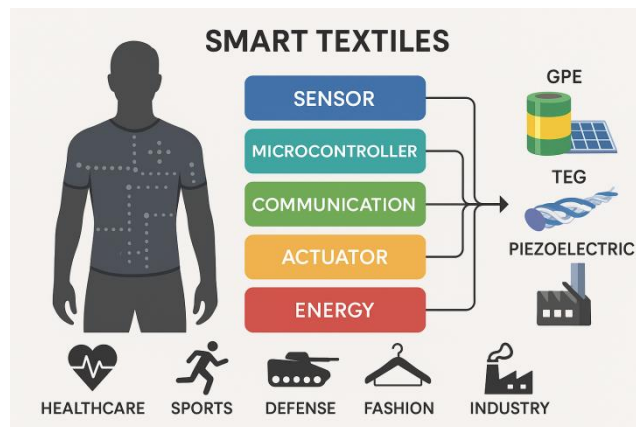


Figure 1. A schematic illustration showing smart textile layers (sensor, microcontroller, communication, actuator, and energy) integrated in wearable systems and their main applications in healthcare, sports, defense, fashion, and industry.

In Uzbekistan, although research on smart textiles is still in early developmental stages, academic and technical institutions such as Namangan Institute of Engineering and Technology, Tashkent State Technical University, and Andijan Mechanical Engineering Institute have initiated interdisciplinary projects. These include PEDOT:PSS-based conductive fabrics, biosensor textiles, and GPE-supercapacitor-integrated modules for smart clothing [9]. Such efforts, though limited in scale, reflect a growing recognition of the role of wearable electronics in health care and industry.

This paper aims to:

- (1) investigate the structural components and design principles of smart textile systems;
- (2) analyze technological approaches for flexible energy integration;
- (3) review international best practices; and
- (4) assess Uzbekistan’s emerging initiatives in this field.

Ultimately, the study seeks to contribute to the scientific understanding and national development of wearable smart clothing by highlighting opportunities and addressing challenges in design, durability, and energy sustainability.

2. Materials and methods. This study was conducted using a comparative analytical approach to systematically examine the structure and functions of smart textile

systems. The research methodology consisted of several key stages, including qualitative content analysis of international scientific literature, system-level decomposition of technological components, and mapping of innovative projects underway at research institutions in Uzbekistan. This multifaceted approach not only facilitated the identification of global best practices but also allowed for a contextual evaluation of their applicability within the national research landscape.

During the system decomposition phase, the technological architecture of smart clothing was divided into five main functional modules. These include: (1) the **sensing layer**, which involves sensitive elements capable of detecting strain, temperature, and biosignals such as heart rate and muscle activity; (2) the **processing layer**, composed of microcontrollers (MCUs, SoCs, FPGAs) that digitize and analyze incoming data in real time; (3) the **actuation layer**, responsible for delivering feedback to the user via LED lights, vibration alerts, or thermal responses; (4) the **communication layer**, which transmits data to mobile devices or IoT platforms using BLE, NFC, or Wi-Fi modules; and (5) the **energy supply layer**, featuring flexible energy harvesting and storage systems such as GPE-based supercapacitors, thermoelectric generators (TEGs), and piezoelectric harvesters. Each module was evaluated based on criteria such as technological compatibility, energy efficiency, ease of integration into fabrics, durability, and washability. Together, these modules define the overall performance and functionality of smart textile systems. Visual diagrams and schematic illustrations of these modules are planned for presentation in subsequent sections of the paper.

3. Results. During the study, the functional modules of smart clothing systems and their technological implementations were identified and analyzed. As shown in **Figure 1** and **Table 1**, the key components of the system include: **sensors, microcontrollers, actuators, communication modules, and energy supply systems**. Each module is equipped with advanced technologies appropriate to its function.

For example, sensors used to measure heart rate (ECG), muscle activity (EMG), and body temperature are based on conductive yarns, strain sensors, and thermoelectric generators (TEGs). Microcontrollers are responsible for digitizing and processing incoming signals and are implemented using platforms such as MCU, FPGA, or AI-enabled SoC units. Physical feedback is provided to the user via actuators including LED lights, vibration motors, and thermoregulators. Wireless communication between the textile and external systems is achieved through BLE, Wi-Fi, or NFC modules. The entire system is powered by integrated energy sources such as GPE-based supercapacitors, piezoelectric yarns, and lightweight solar elements.

Figure 2 illustrates the interconnectivity between the functional modules of smart textiles (on the left) and their practical application domains (on the right). Each module is linked to one or more domains, demonstrating both the modular relevance and potential integration breadth. For example, the energy module supports every domain, while sensing technologies are critical for healthcare and safety.

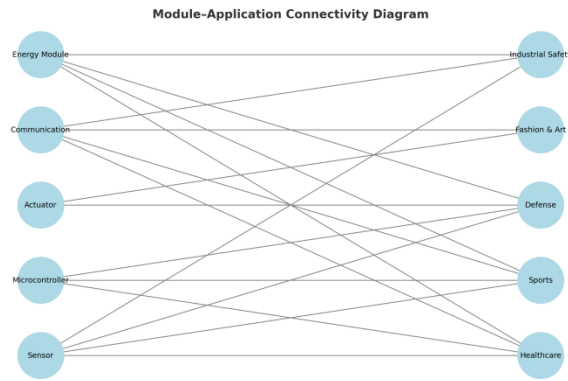


Figure 2. Connectivity diagram between smart textile modules and application domains. (Source: Author's illustration).

Table 1 provides a systematic classification of each module, its function, and the key technologies used. This matrix serves as a methodological foundation for designing smart clothing systems and selecting optimal components for performance and durability.

Table 1. Functional modules of smart textiles and their technologies. (Source: Author, based on research findings)

Module	Function	Technologies used
Sensor	measures ecg, emg, temperature	conductive yarns, strain sensors, teg
Microcontroller	analyzes and digitizes signals	mcu, fpga, ai-enabled soc
Actuator	provides haptic or visual feedback	vibrating modules, led, thermoregulators
Communication	transfers data wirelessly	ble, wi-fi, nfc
Energy Module	powers entire system	gpe-supercapacitors, piezo yarns, solar

These modules are currently applied across a wide range of fields. In **healthcare**, products like *Hexoskin*, *Sensoria*, and *Vital Jacket* allow for continuous monitoring of ECG, respiration, and sweating. In sports, platforms such as *Athos* and *OMsignal* provide real-time analytics of muscle performance and hydration, enabling personalized training optimization. In the military, the U.S. Army's *Smart Uniform* is designed to detect injuries and environmental stressors in combat conditions. In fashion and art, brands like *CuteCircuit* integrate LEDs and social media-responsive elements into garments, enabling interaction with music or user motion. In industrial safety, smart fabrics detect temperature, gas emissions, or pressure fluctuations in hazardous environments to enhance worker protection.

The results demonstrate that the proper selection and integration of functional modules significantly determine the overall performance of smart textile systems. Each layer's technological advantages, energy consumption, and fabric compatibility must be assessed holistically. These findings serve as the basis for the next section, which discusses technological trends, commercialization strategies, and national innovation alignment.

4. Discussion. One of the most critical technological bottlenecks in the development and widespread adoption of smart textiles is ensuring reliable and efficient **energy autonomy**. Conventional lithium-based batteries are often bulky, rigid, and sensitive to environmental factors such as moisture and temperature, making them unsuitable for seamless integration into washable and flexible garments. As a result, contemporary research has pivoted towards advanced energy harvesting and storage systems tailored specifically for textile applications.

Among these, gel polymer electrolyte (GPE)-based supercapacitors have emerged as a promising alternative due to their high flexibility, rapid charging, and intrinsic safety when compared to traditional batteries [10]. Similarly, thermoelectric generators (TEGs) and piezoelectric fibers offer the potential to convert body heat and mechanical movement into usable electrical energy, thereby enabling self-powered wearable systems [11]. Furthermore, self-healing ion gels and conductive polymer composites such as PEDOT:PSS and graphene-based fabrics help maintain electrical continuity even under mechanical strain, thereby extending the lifespan and durability of smart clothing [8].

Comparative international studies reveal that leading institutions in countries like the USA, South Korea, Japan, and Switzerland are rapidly advancing toward fully integrated modular systems, incorporating AI-assisted control units, graphene nanomaterials, and flexible sensors. In contrast, smart textile research in Uzbekistan is still in its nascent stage, focusing primarily on proof-of-concept projects such as PEDOT:PSS-coated strain-sensitive fabrics, biosensor-enhanced yarns, and GPE-functionalized textile patches developed by regional technical universities.

Nonetheless, the interdisciplinary integration of mechatronics, polymer science, and textile engineering within Uzbekistan's academic landscape is gradually forming a fertile ground for scalable production. Pilot projects at institutions such as Namangan Institute of Engineering and Technology and Tashkent State Technical University are actively exploring materials like CNT-based conductive inks, biodegradable sensors, and nano-enhanced fabrics, aligned with global sustainability goals.

Despite this progress, commercialization and mass production of smart textiles still face formidable challenges. These include:

- **Regulatory hurdles** concerning safety and material certification,
- **Limited washability and mechanical durability** under real-world use,
- **High production costs**, especially for nanomaterials and microelectronics.

Overcoming these barriers requires not only scientific innovation but also policy support, industry-academia collaboration, and international knowledge transfer. In this regard, establishing national-level research consortia and engaging with global smart textile networks would significantly accelerate Uzbekistan's capacity to develop, validate, and commercialize wearable technologies.

5. Conclusion. Smart textiles are revolutionizing the landscape of wearable technologies by seamlessly integrating flexible electronics, sensing layers, energy systems, and interactive functionalities into conventional fabrics. This study has conducted a modular examination of smart textile systems, highlighting five core

components—sensors, microcontrollers, actuators, communication units, and energy modules—and analyzing their technological implementations across various application domains including healthcare, sports, defense, fashion, and industry.

Through case studies of global leaders such as MIT, KAIST, and CAS, the paper illustrated the advancement of high-performance energy systems like GPE-supercapacitors, TEGs, and piezoelectric yarns. In parallel, the review of Uzbekistan's emerging efforts—from biosensor textiles to PEDOT:PSS-based smart fabrics—demonstrates a promising foundation for future innovation, despite current limitations in commercialization and infrastructure.

To support the sustainable development and scalable deployment of smart textiles in Uzbekistan and similar emerging economies, the following strategic recommendations are proposed:

1. **Establish interdisciplinary research laboratories** that integrate materials science, electronics, and information technologies to foster system-level innovation.
2. **Encourage international collaborations and joint ventures** for advanced knowledge transfer, testing standards, and access to frontier materials and devices.
3. **Prioritize the development of modular, washable, and self-powered textile platforms** that can meet real-world usability requirements in both consumer and industrial markets.

By implementing these strategies, Uzbekistan can accelerate its participation in the global smart textile value chain and contribute to the advancement of next-generation wearable technologies with localized solutions and competitive expertise.

References:

1. MIT Media Lab. Wearable computing and smart textiles: Early experiments and frameworks // MIT Research Archives. – 1995.
2. Stoppa M., Chiolerio A. Wearable electronics and smart textiles: A critical review // *Sensors*. – 2014. – T. 14, №7. – B. 11957–11992. DOI: <https://doi.org/10.3390/s140711957>
3. Castano L.M., Flatau A.B. Smart fabric sensors and e-textile technologies: A review // *Smart Materials and Structures*. – 2014. – T. 23, №5. – B. 053001.
4. IDTechEx. Wearable Technology Market Forecasts 2023–2033. – 2023. URL: <https://www.idtechex.com/en/research-report/wearable-technology> (kun: 13.07.2025)
5. Kim J., et al. Epidermal electronics // *Science*. – 2011. – T. 333, №6044. – B. 838–843.
6. Lee S.-Y., Kim D.-H., Yoon J. Self-healing and highly stretchable gel polymer electrolytes for flexible supercapacitors // *Advanced Materials*. – 2020. – T. 32, №30. – B. 1906679. DOI: <https://doi.org/10.1002/adma.201906679>
7. Tanaka H., Yamashita T., Sato M. Fiber-integrated thermoelectric generators for wearable energy harvesting // *Nano Energy*. – 2019. – T. 60. – B. 567–574. DOI: <https://doi.org/10.1016/j.nanoen.2019.03.032>

8. Cheng H.-M., Zhang Y., Li J. Graphene-based textile sensors and self-healing ion gels for smart wearable electronics // *Advanced Functional Materials*. – 2019. – T. 29, №8. – B. 1808242. DOI: <https://doi.org/10.1002/adfm.201808242>
9. Komilov Y., Shodmonov J., Rakhmatova Z. Development of PEDOT:PSS-based biosensor fabrics in Uzbekistan // *Uzbek Journal of Materials Science*. – 2024. – T. 6, №1. – B. 34–41.
10. Kim J., Lee M., Rogers J.A. Advances in epidermal electronics and their integration into smart garments // *Nature Electronics*. – 2021. – T. 4, №4. – B. 195–204. DOI: <https://doi.org/10.1038/s41928-021-00554-1>
11. Park S., Kim H., Jeong U. Nanofiber-based piezoelectric materials for wearable self-powered sensors // *Nano Letters*. – 2021. – T. 21, №6. – B. 2456–2463. DOI: <https://doi.org/10.1021/acs.nanolett.0c04887>

C O N T E N T S

TECHNICAL SCIENCES: COTTON, TEXTILE AND LIGHT INDUSTRY

Dustkobilov U.	
Circular economy practices in the textile industry: Current status, indicators, and development opportunities	3
Kuldashov G., Oripov J.	
Forecasting the temperature gradient of cotton revolt	10
Kuldashov G., Oripov J.	
Optoelectronic three-wave moisture meter of raw cotton	16
Umarov A.	
Research on the optimization of the saw gin's roll box	26
Tursunov A., Sharibaev N.	
Techniques and devices for mitigating environmental pollution in cotton processing industries	36
Ganikhanov Kh., Mavlyanov A., Abdusamatov A., Mirzaumidov A.	
Effect of the forces on the separation of fiber flow from the saw in an improved lower fiber removal device	43
Nurulloyeva Kh., Abdusamatov A., Mirzaumidov A.	
Experimental determination of the load on the multifaceted columns on the elastic supports of the cotton ginner	49
Muradov A.	
Study of the dynamics of the drive mechanism of moving needles	54
Ismatullayev N., Shamsiyeva M.	
Development of technology for producing leather from african catfish skins	59
Rahmatova S.	
Theoretical study of the quality indicators of newly structured knitted fabrics based on a mathematical model	65
Parpieva N., Kayumov J., Parpiyev D., Lastochkin P.	
Theory of torsional vibrations of grooved cylinders	71
Komilov Sh., Mamadaliyev N., Jurayeva G.	
Quality indicators of cotton fiber analyzed	83

TECHNICAL SCIENCES: AGRICULTURE AND FOOD TECHNOLOGIES

Sobirova M., Mohamed R., Farmonov J., Samadiy M.	
Impact of calcium chloride on the cheese yield during swiss cheese manufacturing process	91

Kurayazov Z., Ravshanov S., Kanoatov X.	
Analysis of the influence of the whitening process during preparation for flouring on the quality of bakery flour made from a mixture of wheat and rye grains	96
Xusanxodjayeva F., Meliboyev M., Ergashev O.	
Development of technology for complex processing of garlic onions	105
Meliboyev M.	
Development of complex processing technology for the secondary mass of watermelons and zucchini	112
Nishonov U., Mominov U.	
Evaluation of organoleptic properties of soft drinks prepared from plant materials	118
Khurmamatov A., Yusupova N., Sarsenbayev N., Mallabayev O.	
Results of determination of bitumen movement modes at different temperatures	124
Yusupova N., Sarsenbayev N., Mallabayev O.	
Results of improving the construction of the plate heat exchange	130

CHEMICAL SCIENCES

Jumayeva D., Zaripbaev K., Oxunjonov Z., Nomonova Z.	
Compositional analysis of raw materials in sorbent production	135
Abdumalikov A., Ummatov O., Mamajonov B., Esonkulova N., Ochilov G.	
Thermal treatment of various samples of low-molecular-weight polyethylene – a by-product of polyethylene production	145
Mamajonova M., Salixanova D., Abduraxmonov E., Ismailova M.	
Energetics of water molecule adsorption on modified bentonite surfaces	153
Abdurahimov A., Abdullayeva F., Usmonova Z.	
Infrared spectroscopic analysis of the purification of sunflower oil from waxy substances using perlite and vermiculite	160
Eshbaeva U., Gökhan Z., Bahri B.	
Theoretical foundations for ensuring the mechanical strength of papers containing collagen hydrolysates	167
Eshbaeva U.	
Research on the printing and technical properties of kraft paper incorporating "cotton cellulose-industrial waste-paculate"	172
Makhkamova D.	
Research on the separation of zinc from metallurgy waste with a mixture of ammonia and ammonium salts	181
Yuldasheva M., Makhkamova D., Turayev Z	188

Study of interaction of components in the H_3BO_3 – KNO_3 – H_2O system	
Juraev M., Siddikov D., Askarova O.	
Aboveground components of salvia sarawschanica	194
Davlatova O.	
Zeolite-based bimetallic composite catalysts for pyrolysis and gasification: chemical technologies for deep biofuel upgrading and conversion intensification	202
Davlatova O.	
Use of BaNaY faujasite zeolite-based bimetallic composite catalysts for deep biofuel purification and selective xylene separation	208
Shamuratova M., Giyasidinov A., Eshmetov I., Nurjanova G.	
On the study of physicochemical properties of soils in the regions of the republic	214
Hoshimov F., Lutpillayeva M.	
Optimized chemical synthesis of stable silver nanoparticles using various reducing and stabilizing agents	220
Sarimsakova N.	
Investigation of the adsorption properties of the sorbent obtained in the process of modification of clinoptilothite in the purification of natural gas from sulfur compounds	227
Kokharov M., Bakhronov Kh., Sultonov A., Jumaeva D., Jumaboeva Z., Gaybullayeva D., Abdumutalova G.	
Adsorption isotherm of hydrogen sulfide on an activated adsorbent derived from hybrid paulownia tomentosa wood	234
Ikramov M., Zakirov B.	
Optimization of the aqueous solubility of monoammonium phosphate, potassium nitrate, and magnesium nitrate via thermodynamic analysis and selective crystallization	243
Nazhimova N., Seitnazarova O.	
Study of the chemical and mineralogical composition of thermal power plant wastes	249

TECHNICAL SCIENCES: MECHANICS AND MECHANICAL ENGINEERING

Berdiev U., Hasanov F., Avazov B., Ostanayev., Viktor M.	
Study of the nature and prospects of practical application of the magnetocaloric effect in energy-efficient cooling systems	256

Sodikov T.	
Research of mechanical part of solar photovoltaic power station	263
Otamirzayev D.	
Calculation of absorption coefficient of organic dye N719 for dye-sensitive solar cell (DSSC)	270
Abdovakhidov M.	
Study on determining the bending and torsional stiffness of packaged working bodies	276
Abdovakhidov M.	
The study torsion fluctuations packet worker organ with provision for influences of the correlation longitudinal acerbity their element	280
Shodmonov J.	
Energy-integrated smart textiles: international trends and prospects for uzbekistan's research ecosystem	285
Djurayev Sh.	
Integrated genetic-differential evolution approach for simultaneous pressure-drop reduction and efficiency enhancement in multi-cyclone dust collectors	292
Mamaxanova Z.	
Technological principles for creating a suit that ensures high reliability and safety in aquatic environments	297
Pirnazarov U.	
Theoretic observation of the cotton movement in the operating camera of the new separator	306
Pirnazarov U.	
Investigation of the interaction between the moving separator screen surface and the cotton mass	315
Yusupov D., Abduraximov D., Muxammadjonov M.	
Determination of energy loss in the magnetic core of oil power transformers under long-term operation conditions	319

ADVANCED PEDAGOGICAL TECHNOLOGIES IN EDUCATION

Abdullayev X.	
Transition function of second-order element	326

ECONOMICAL SCIENCES

Isroilov R.	
Criteria, indicators and laws of small business development	331

Isroilov R.

Concept of assessment of the economic development potential of small business and its evaluation **340**

Bustonov M.

Econometric analysis of the activities of multi-sectoral farms **348**

Bustonov M.

Global digitalization: paths and problems **356**

Kadirova Kh.

Prospects for development and improvement of the mechanism of functioning of the stock market **366**
