

Research on Design Path and Industrialization of Wearable Clothing Driven by Intelligent Perception

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Abstract: Wearable clothing has become an ideal carrier of intelligent sensing technology by virtue of its seamless fit with human body. However, how to realize the organic unity of functional integration and aesthetic expression is still the core proposition that restricts industrial development. This study puts forward an innovative framework of "perception-structure-interaction", which is studied from three levels: technology, design and industry. On the technical level, a multi-modal sensor fusion network is constructed to optimize the component layout; On the design level, a modular standard interface system is established to realize the flexible replacement of functional units; At the industrial level, explore the collaborative manufacturing model of "textile factory+chip foundry". The research also puts forward the design method based on ergonomic modeling and the user-centered interactive experience design strategy. In terms of industrialization implementation path, through supply chain reconstruction, quality control and market penetration strategy, technology-supply chain-market three-terminal coordination is realized. The research in this paper provides a new idea for solving the paradox of "technology flaunting skills" and "market paying" in smart clothing industry, and is expected to promote the market popularization and industrial development of smart clothing.

Keywords: Industrialization; wearable clothing; intelligent perception.

1. Introduction

Traditional smart watches, bracelets and other hard devices are difficult to meet the deep needs of medical monitoring, exercise enhancement, emotional interaction and other scenes because of their poor wearing comfort and single data acquisition dimension. In this context, wearable clothing has become an ideal carrier of intelligent perception technology by virtue of its natural advantages of seamless fit with human body. However, how to break through the binary opposition between "technology stack" and "clothing essence" and realize the organic unity of functional integration and aesthetic expression is still the core proposition that restricts industrial development.

The existing research has made breakthroughs in the miniaturization of sensors and self-supply of energy, but there are still three major faults in the system design: first, the collaborative mechanism between physiological signal acquisition and clothing structure design has not been established, which leads to the conflict between sensor position and human motion joints; Secondly, the reliability standard of flexible electronics module is missing, and the Mean time between failures (MTBF) of existing products is less than 1/3 of that of hard equipment [1]. Third, the technical language of each link in the industrial chain is fragmented, and the cooperation efficiency between textile enterprises and electronic manufacturers is less than 40% [2]. These contradictions have made the penetration rate of the global smart clothing market stagnate for a long time, far lower than that of smart watches.

This study breaks through the traditional design paradigm and puts forward an innovative framework of "perception-structure-interaction": building a multi-modal sensor fusion network at the technical level, and optimizing the component

layout through biomechanical simulation; Establish a modular standard interface system in the design layer to realize hot plug replacement of functional units; Explore the collaborative manufacturing mode of "textile factory+chip foundry" at the industrial level. It provides a new idea for solving the paradox of "technical dazzle" and "market pays the bill".

2. Construction of Intelligent Perception Technology System

The construction of intelligent perception technology system needs to comprehensively consider many aspects such as perception dimension design, material innovation breakthrough and data interaction architecture (Figure 1). Through the organic combination of these aspects, it can provide strong technical support for the design and industrialization of smart wearable clothing.

2.1. Perceptual dimension design

Perception dimension design is the basis of intelligent perception technology system, which involves how to enhance users' perception experience through design. In urban design, the design of perception dimension can explore the relationship between urban design and multiple needs from the psychological process of feeling, perception, cognition and behavior [3]. For example, urban design should deepen and expand from the multiple related information between people and the environment, and directly face the creation of places and the promotion of atmosphere [4]. Perceptual dimension design can also create and convey information through the elements of visual design, such as color, shape, line, texture, space and layout, so that the audience can easily understand and accept the conveyed information [5].

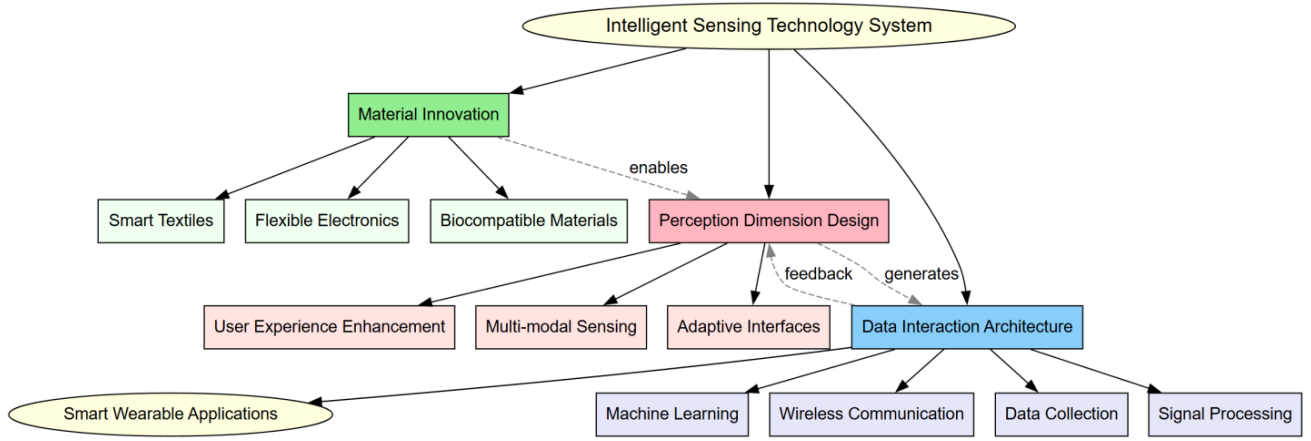


Figure 1. Intelligent perception technology system

2.2. Breakthrough of material innovation

Material innovation is an important part of intelligent sensing technology system, which involves how to improve the performance of sensing technology through the research and development of new materials. For example, the research team has developed a new type of metamaterial, which can reduce the temperature without consuming energy, providing new possibilities for smart wearable clothing [6]. Material innovation includes how to accelerate the research and development process of new materials through AI technology, such as screening and optimizing the design scheme of metamaterials through AI model.

2.3. Data interaction architecture

Data interaction architecture is the core of intelligent perception technology system, which involves how to realize the function of intelligent perception through data collection, storage, processing and analysis. Data architecture is the link between business and system, which includes models, strategies, rules and standards that manage the collection, storage, arrangement, integration and use of data in an organization [7]. In the design of smart wearable clothing, the data interaction architecture needs to consider many aspects such as data subject domain, data flow, logical data model, data distribution and physical data model [8]. The data interaction architecture needs to consider how to improve the efficiency and accuracy of data processing through AI technology, such as optimizing the data governance process through AI evaluation model group.

3. Intelligent Clothing Design Methodology

3.1. Ergonomic modeling

Based on the in-depth study of human body structure, movement law and physiological characteristics, an accurate human body model is constructed by using advanced measurement technology and three-dimensional modeling software. This model not only covers the static size and shape of the human body, but also simulates the dynamic movements and posture changes of the human body, providing a basic framework that fits the human body for the design of smart clothes [9].

Through 3D scanning, anthropometry and other equipment to obtain a large number of human data, including the size, proportion and joint range of motion of various parts of the body, combined with ergonomic experiments, the pressure

distribution and muscle activity of the human body in different postures are analyzed. Using professional three-dimensional modeling software, the collected data are integrated and processed to create a high-precision human digital model. In the process of modeling, factors such as human body curve, muscle trend and bone structure are fully considered to ensure the authenticity and accuracy of the model. With the help of motion capture technology and mechanical analysis software, the motion of human body in different motion states is simulated and analyzed, so that the mannequin can present various natural motion postures, which provides a basis for the adaptive design of smart clothing in the process of motion.

The smart clothes designed according to the ergonomic model can better fit the human body curve, reduce the sense of oppression and friction discomfort, and improve the comfort of wearing. For example, in sports smart clothing, sensors and electronic components should be arranged reasonably to avoid skin irritation, and at the same time, to ensure that the clothing will not restrict the body's activities during sports. Based on the analysis of the human model, we can accurately determine the best positions of various functional modules on smart clothing, such as the placement positions of sensors, so as to achieve more accurate data monitoring and interactive functions. For example, placing the heart rate sensor near the heart can obtain heart rate data more accurately.

3.2. Modular design system

The smart clothing is decomposed into several independent functional modules, each module has a specific function and interface, and is combined together through standardized connection to form a complete and flexible configuration system. This design concept is similar to building blocks, which is convenient for rapid customization and adjustment according to different needs and usage scenarios.

According to the functional requirements of smart clothing, it is divided into central computing module, peripheral electrical module (such as sensor module, communication module, power module, etc.), executive module (such as heating, cooling, vibration, etc.) and basic clothing module [10]. Each module has clear functions and performance indicators, and the interfaces between them are standardized, which is convenient for connection and replacement. Formulate unified interface specifications, including electrical interface, mechanical interface and communication interface, to ensure stable and reliable connection and communication between different modules. For example, the

universal serial communication protocol is adopted to realize data transmission between modules, and standardized plugs and sockets are designed to facilitate the insertion and replacement of modules. Each functional module is integrated and packaged according to the design requirements, making it a compact, beautiful and easy-to-wear whole. In the process of integration, pay attention to the rationality of the layout between modules, avoid electromagnetic interference and line confusion, and consider the overall weight and balance of clothing.

When a functional module fails or needs to be upgraded, only the corresponding module needs to be replaced, and the whole garment does not need to be greatly changed, which reduces the maintenance cost and difficulty and prolongs the service life of the product. With the continuous development of sensor technology, the monitoring performance of smart clothing can be improved only by replacing more advanced sensor modules. Users can choose different functional modules to combine according to their specific needs to realize personalized smart clothing customization. Athletes can choose to be equipped with different sensors and auxiliary function modules according to training items, while ordinary consumers can focus on daily health monitoring and comfort function selection.

3.3. Interactive experience design

Focusing on users, we pay attention to the interaction process and feelings between users and smart clothes. By designing intuitive, natural and convenient interaction methods, users can easily operate and control various functions of smart clothes, and at the same time get timely and accurate feedback information, thus improving the user experience. A variety of interactive means, such as touch, gesture recognition, voice control, eye tracking, etc., are adopted to meet the operational needs of different users in different scenarios. For example, in smart sportswear, you can

adjust music playback or view sports data through gesture sliding; In medical rehabilitation smart clothing, for patients with mobility difficulties, voice control can realize convenient operation of clothing functions. Establish an effective feedback system. When users operate, smart clothes can give feedback in time through visual, auditory, tactile and other ways, so that users can know whether the operation is successful or not and the current functional status. Prompt the user to receive a notice or complete an operation through the flashing or vibration of the LED light; Display detailed functional information and data feedback on the display screen. Considering the emotional needs of users, emotional elements are integrated into the interaction process, so that smart clothing is not only a functional product, but also can resonate with users. According to the user's emotional state, automatically adjust the color and pattern of clothing or play soothing music to provide psychological comfort and companionship for users.

Simple and easy-to-use interactive design and good feedback mechanism can reduce the difficulty and learning cost of users using smart clothing, make more users willing to accept and use smart clothing products, and promote the market popularization of smart clothing. Emotional design can increase users' love and dependence on smart clothes, make users feel more care and fun during use, and thus improve users' loyalty to products and reuse rate.

4. Industrialization Implementation Path

The core of the industrialization path lies in the synergy of technology, supply chain and market (Figure 2). Flexible production is realized through intelligent supply chain, product reliability is guaranteed by strict quality control, and finally the market is opened by scene application and ecological cooperation.



Figure 2. Technology-supply chain-market three-terminal coordination

4.1. Supply chain reconstruction strategy

Enterprises should reconstruct the supply chain strategy through regionalization and localization, digital transformation and strengthening partnership. Specifically, the establishment of regional production centers can shorten delivery time, reduce logistics costs, and rely on local resources and technological advantages; At the same time, use the Internet of Things and big data analysis to improve the transparency and response speed of the supply chain, and combine blockchain technology to ensure the traceability of materials; Work closely with suppliers to jointly develop new materials and technologies to enhance the flexibility and adaptability of the supply chain.

4.2. Quality management system

Enterprises should build a quality control system covering standardized processes, rigorous testing and continuous improvement. By formulating unified quality standards and operating procedures, we can ensure that all links from raw material procurement to finished product delivery meet high quality requirements; Test the durability, comfort and functionality of intelligent components and textiles to ensure product reliability and user experience; Establish a feedback mechanism and collect user data to promote continuous optimization of product quality and quickly respond to market changes.

4.3. Market penetration strategy

Enterprises should achieve market penetration through target market segmentation, brand building and education, channel expansion and cooperation and alliance. First, provide customized solutions according to the needs of different groups of people, such as athletes, the elderly or patients with chronic diseases; Enhance brand awareness through marketing activities, popularize product functions and values to consumers, and enhance awareness; Actively expand online platforms, health clubs, gyms and other diversified sales channels to expand product coverage; Finally, establish cooperative relations with industry leaders or technology companies, launch joint brand products, and increase market share with the help of external resources and brand influence.

5. Conclusion

Put forward an innovative framework of "perception-structure-interaction". On the technical level, the multi-modal sensor fusion network and biomechanical simulation optimization layout are constructed; On the design level, a modular standard interface system is established to realize hot plug of functional units; At the industrial level, explore the "textile factory+chip foundry" collaborative manufacturing model. The research also covers intelligent perception technology system, ergonomic modeling, modular design and user-centered interactive experience, and promotes industrialization from supply chain reconstruction, quality

control to market penetration, and finally realizes the deep application of smart clothing in medical monitoring, sports enhancement, emotional interaction and other scenes, and promotes the organic unity of functionality and aesthetics.

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References

- [1] Arwa Alsubhi, Reza Ghaumy Anaraky, Simeon Babatunde, Abu Bakar, Thomas Cohen, Josiah Hester... & Jacob Sorber.(2024).User-Centered Perspectives on the Design of Batteryless Wearables.International Journal of Human-Computer Interaction, 40(23),8025-8046.
- [2] Kieran G Stakem, Freddie J Leslie & Georgina L Gregory.(2024). Polymer design for solid-state batteries and wearable electronics.. Chemical science,15(27),10281-10307.
- [3] Steve Burrow, Lindsay Clare, Bernard Stark,Steve Beeby & Neil Grabham.(2024).Design Considerations and Experimental Testing of a Wide-Area Inductive Power Transfer (IPT) System for Body-Worn Electronics.Energies,17(14),3367-3367.
- [4] Qing Jiang, Yuhang Wan, Yi Qin, Xueru Qu, Mi Zhou, Siqi Huo... & Hualing He.(2024).Durable and Wearable Self-powered Temperature Sensor Based on Self-healing Thermoelectric Fiber by Coaxial Wet Spinning Strategy for Fire Safety of Firefighting Clothing.Advanced Fiber Materials, 6(5), 1387-1401.
- [5] Jiaoli Piao,Yehyoun Kim,Ru Han,Darinka Popov & Sumin Koo.(2024).Explorations of clothing-typed wearable platforms: satisfaction evaluations and displacement measurements. International Journal of Clothing Science and Technology, 36(1), 68-83.
- [6] Wang Qi,Wang Mengfan,Sun Jiali,Zhang Xiaolin,Chen Weichun,Yu Xichen & Fan Wei.(2023).Different assembled nano-MnO₂ fiber supercapacitors applied for smart wearable clothing. Textile Research Journal,93(21-22),4781-4791.
- [7] Lee Sung Kyu & Koo Sumin.(2022). Development of three-dimensional printed cultural fashion products using symbols of longevity. Textile Research Journal, 92(21-22),4484-4500.
- [8] Lee Hyojeong & Lee Yejin.(2023). Optimal prototype design of dry textile electrode-based compression pants for surface electromyography measurements. International Journal of Clothing Science and Technology,35(1),120-134.
- [9] Zhang Tao,Ratajczak Adam Michael,Chen Hui,Terrell John A & Chen Chengpeng.(2022).A Step Forward for Smart Clothes—Fabric-Based Microfluidic Sensors for Wearable Health Monitoring..ACS sensors,7(12),3857-3866.
- [10] Jungnickel Kat.(2023). Clothing Inventions as Acts of Citizenship? The Politics of Material Participation, Wearable Technologies, and Women Patentees in Late Victorian Britain.Science, Technology, & Human Values,48(1),9-33.