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Industrial design of wearable intelligent devices based on wireless networks

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A R T I C L E I N F O

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A B S T R A C T

In the current digital era, intelligent wearable devices have become an indispensable part of people's lives and work. Through their unique design and equipped hardware and software technologies, they enable users to quickly and efficiently acquire and process personal data, thus achieving better life and work efficiency. In these devices, wireless sensing technology plays a very important role. By combining wireless networks, sensing technology, and human-computer interaction, these devices provide rich functionality and a convenient user experience. However, the current wearable intelligent devices are lacking in specific applications, and there is a risk of data privacy leakage. Through control variable method, comparative method and experimental method, the experimental part conducted research and exploration on counting accuracy, distribution range and accuracy of heart rate measurement under different exercise states, data transmission speed under different wireless connection methods, and performance testing of wearable intelligent devices (high-temperature environment performance; low-temperature environment performance; waterproof level indicators; battery life). After testing, the overall step accuracy of the product designed in this article was above 96.5 %, and the overall measurement accuracy of heart rate under various exercise states was above 92 %. The data transmission speed is fast and stable, and the other evaluations are relatively excellent. Wearable intelligent devices based on wireless networks have broad application prospects in improving quality of life, health management, and intelligent services. With the advancement of technology and the continuous changes in user needs, wearable devices can continue to develop and bring more convenience and intelligent experiences to people's daily lives.

1. Introduction

With the continuous development of technology, wearable intelligent devices are becoming increasingly popular and an indispensable part of people's daily lives. Among them, wearable intelligent devices based on wireless networks have great potential in function and interaction design [1]. These devices can not only achieve rich functions such as health monitoring, motion tracking, notification reminders, etc., but also interact with external devices and cloud services through wireless network connections, expanding their application scope and convenience.

The development of wearable intelligent devices has greatly improved people's health levels. Karim Bayoumy believed that technological innovation has promoted the development of commercial wearable intelligent devices and provides some suggestions, providing a simple and practical guide for clinical doctors to personalize according to their specific practical needs, in order to accelerate the integration of these devices into clinical workflows and achieve optimal patient care [2]. Jithin K. Sajeev believed that consumers' acceptance of smart devices and wearable technology is constantly improving, and wearable smart devices can help to conduct non-invasive and dynamic evaluation of many cardiac indicators, including heart rate and rhythm [3]. Zhu Wang believed that with the recent surge in intelligent wearable devices, it is possible to obtain human physiological and behavioral data in a more convenient and non-invasive way. Based on this data, he developed various systems or applications to identify and understand human behavior, including physical activity and mental state [4]. Apurva Adapa believed that the design and image related factors of wearable smart devices are particularly important in the user community. He collected and analyzed data through a stepwise approach, providing insights into key design standards to better meet user needs and interests [5]. Xiaojun Zhang believed that the analysis of convolutional neural network in motion recognition is conducive to the research of human motion recognition based on deep learning and intelligent wearable devices in motion. Because of low energy consumption and low cost, they have been widely used in various sports events, which can improve the sensitivity and accuracy of sensors in intelligent wearable devices and promote their application in various sports events [6]. These

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scholars' research on wearable intelligent devices is mainly reflected in their functions and applications, and there is less research on the combination of wearable intelligent devices and wireless networks.

Applying wireless networks to wearable intelligent devices can effectively improve the data transmission efficiency of devices. Saad Khan believed that more and more health data are perceived from health based wearable Internet of Things devices to provide much-needed fitness and health tracking [7]. Zhipeng Song believed that in recent years, motion tracking on mobile and wearable devices through inertial measurement unit has attracted great attention, and high-precision inertial measurement unit tracking can be applied to various applications, such as indoor positioning system, gesture recognition, text input, etc. [8]. Linda Taylor believed that although there is a correlation between the medical Internet of Things, traditional Chinese medicine, healthcare, and body sensor networks, and intelligent wearable devices, there is limited research and shortcomings [9]. Furrukh Sana believed that collecting and analyzing long-term data based on wearable devices, smartphones, and other dynamic sensors can provide reliable diagnosis and is implementing a new healthcare model [10]. Xie, Liping intended to provide up-to-date literature on wearable devices for smart healthcare. A systematic review is provided, from sensors based on nanomaterials and nanostructures, algorithms, to multifunctional integrated devices with stretchability, self-powered performance, and biocompatibility. Typical electromechanical sensors are investigated with a specific focus on the strategies for constructing high-performance sensors based on nanomaterials and nanostructures [11]. Xu Yanxia compared an objective wearable sleep monitoring device with polysomnography (PSG) to provide a reference for OSA screening in a large population. Compared with the PSG, WISM exhibits good sensitivity and specificity for the diagnosis of OSA. This small, simple, and easy-to-use device is more suitable for OSA screening in a large population because of its single-step application procedure [12].

These scholars' research on wearable devices based on wireless networks is mainly distributed in the medical field, and there is less research on wearable intelligent devices in daily life. The above research results also did not consider the issue of data transmission in the optimization model of wireless sensor networks. The wearable intelligent device proposed in this article for wireless networks can improve overall measurement accuracy, and the data transmission speed is fast and stable. Other evaluations are relatively good.

Ergonomic design is a crucial consideration when designing these wearable devices. The comfort, fit, and wearing experience of the device are crucial to the user experience. In addition, reasonable function and interaction design can improve the ease of use and user satisfaction of the device. At the same time, energy management, waterproof performance, and durability are also design elements that cannot be ignored to ensure the long-term reliability and stability of the equipment. This paper discussed the industrial design of wearable intelligent devices based on wireless networks, including ergonomic design, functional and interaction design, network connection and data transmission, energy management, waterproof performance and durability design. This article analyzed the importance of these design elements and introduced relevant algorithms and technologies to provide a comprehensive perspective and guidance to help designers and manufacturers create better wearable intelligent devices.

2. Industrial design and implementation of wearable intelligent devices based on wireless networks

Wearable intelligent devices based on wireless networks refer to intelligent devices that communicate and transmit data through wireless network connections, which can be directly worn on the human body and provide various functions and services. This type of device typically communicates with other devices such as mobile smartphones, tablets, or cloud servers, enabling data transmission and real-time interaction through wireless connectivity technologies such as Bluetooth, Wi-Fi, or mobile networks. They can collect, analyze, and transmit various data, such as health monitoring data, motion tracking data, notification reminders, etc., providing users with real-time personalized services. At present, wearable intelligent devices based on wireless networks have made certain progress and applications. Wearable intelligent devices based on wireless networks have a wide range of application scenarios in various fields, including but not limited to the followings: health management: People can monitor their own health data through wearable devices, such as heart rate, sleep quality, exercise, etc., to conduct personalized health management and guidance; sports training: sports enthusiasts can use wearable devices to record and analyze sports data, such as step count, distance, calorie consumption, etc., to optimize training effectiveness and improve sports performance; intelligent assistant: wearable devices, as intelligent assistants, can provide functions such as message reminders, calendar management, voice assistant, navigation, etc., making it more convenient for people to manage their lives and work; medical monitoring: medical institutions can use wearable devices to monitor patients' physical conditions, obtain health data in real time, and provide accurate medical monitoring and intervention.

2.1. Ergonomic design

The ergonomic design of wearable intelligent devices based on wireless networks can ensure the compatibility, comfort, and convenience between the device and the user's body, providing a better wearing and operating experience. The following are several key points to consider in ergonomic design: 1) Size and weight: Wearable devices should consider the user's body size and the size of various parts. The size of the equipment should be moderate, neither too large to be bulky nor too small to be unstable or difficult to operate. In addition, the weight of the device should also be lightweight to avoid placing too much burden on users. 2) Bending and curve design: The design of wearable devices should consider the curves and joint movements of the human body. For example, for devices worn on the wrist, there should be a soft strap or adjustable buckle to adapt to different wrist sizes and range of motion. At the same time, the appearance of the device should also avoid being too sharp or angular to avoid discomfort to the user. 3) Wearing stability: Wearable devices are ensured to maintain stability during the wearing process. Suitable fixing mechanisms, adjustable watch straps, or other fixing devices are used to ensure that the device can tightly fit the user's body parts without loosening or sliding. 4) Material selection: Comfortable, breathable, and compatible with human skin materials are selected to avoid allergies or irritation. In addition, materials that are easy to clean and prevent sweat and moisture accumulation should be considered to maintain the dryness and hygiene of the equipment.

By considering the above factors comprehensively, the ergonomic design of wearable intelligent devices based on wireless networks can achieve good adaptation between devices and users, providing a comfortable, stable, and easy to operate user experience.

2.2. Function and interaction design

The function and interaction design of wearable intelligent devices based on wireless networks need to fully consider user needs and usage scenarios to provide convenient, intelligent and personalized experiences. The functional design should include accurate sensors and algorithms to monitor and record users' health status and exercise activities in real-time. The interaction design shall provide clear data display and statistics so that users can understand their own health and activities. The functional design should support multiple message sources and types, and provide flexible notification management methods, such as filtering, priority setting, and custom notification vibration modes. A concise message display and operation method should also be provided for users to quickly browse and process notifications. Wearable devices can achieve more natural and convenient interaction through gesture recognition and voice control. Gesture recognition allows users to perform functional control by tapping, sliding, rotating and other gesture operations, as shown in Fig. 1 [13,14]. Voice control can be achieved through voice recognition and voice commands, enabling users to interact and operate with devices through voice.

In Fig. 1, it can be seen that the control gestures of intelligent wearable devices mainly include click type gestures, sliding gestures, and rotating gestures.Among them, click gestures are used to control devices through a single or multiple click gesture; The sliding gesture is achieved by sliding the finger on the device screen to control the device. The rotation gesture is achieved by rotating the fingers on the device screen to control the device.

At the same time, wearable devices can provide intelligent assistants and personalized suggestions to help users manage their schedules, provide health advice, or recommend personalized activity goals. Interaction design shall provide intuitive interface and simple operation mode, so that users can interact with assistants and receive useful suggestions. Wearable devices can connect to the internet through wireless networks, providing networking and social functions. For example, users can receive instant messages, view social media updates, or share sports achievements through their devices. The functional design should support stable wireless connection and data transmission, while providing a friendly interface and operation mode, as shown in Fig. 2, allowing users to easily enjoy networking and social experiences. Finally, the function and interaction design of wearable devices should consider the development of application ecosystem.

In Fig. 2, the intelligent wearable device tablet operation interface can achieve user movement distance query, heart rate value query, environmental temperature query, and body temperature query. To sum up, the function and interaction design of wearable intelligent devices based on wireless networks should focus on health and motion monitoring, message and notification management, gesture and voice control, intelligent assistants and personalized advice, networking and social functions, and the development of application ecosystems.

2.3. Network connection and data transmission

Wearable intelligent devices based on wireless networks rely on wireless connection technology for network connection and data transmission. Wearable devices can use various wireless connection technologies, including Bluetooth, Wi Fi, Near Field Communication (NFC), and Mobile Network. Choosing a wireless connection technology that suits the device's needs is an important factor in ensuring stable connection between the device and other devices or the Internet [15,16]. Users need to pair and connect wearable devices with other devices (such as smartphones) to establish communication links. Usually, pairing and connection between devices can be achieved through Bluetooth or other wireless connection technologies.

Wearable devices typically transmit collected data through wireless networks to other devices or cloud servers for storage and analysis. Data synchronization can be achieved through wireless connection technology to ensure the timeliness and integrity of data. Cloud services provide a centralized platform for storing and processing data, enabling users to access and manage their health and activity data across multiple devices [17,18]. In order to optimize data transmission efficiency, it is necessary to conduct data transmission efficiency analysis in wireless sensor networks. The analysis process can be carried out as follows:

Wireless sensor networks are divided into a series of units of equal length that do not intersect. Each unit can be a region, node set, or other appropriate partitioning method, determined based on the characteristics and requirements of the network [19]. It is supposed that A_{pi} represents the bounded domain of a function, and the condition of $A_{pi} = \{A_{p1}, A_{p2}, ..., A_{pi}\}$ should be satisfied. D_n represents an n-dimensional space, and $S = \{P_{D1}, P_{D2}, ..., P_{Dn}\}$ represents a data distribution point on the n-dimensional space. $mean(c)$ is the Centroid of unit c.

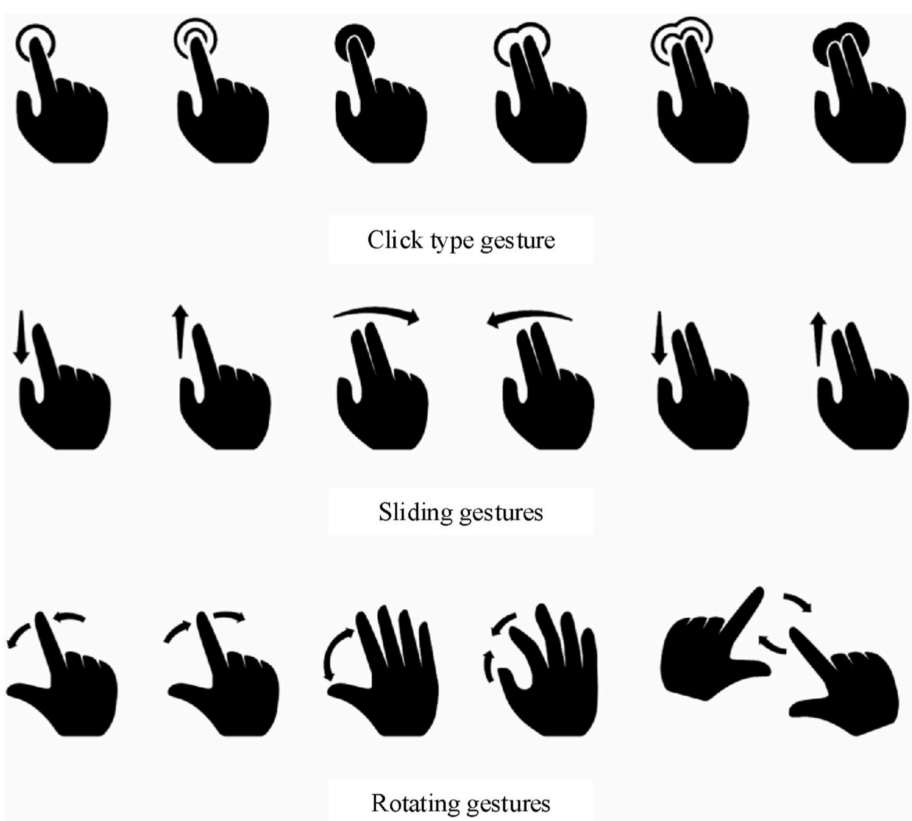

Fig. 1. Intelligent wearable device control gesture.

Fig. 2. Intelligent wearable device tablet operation interface.

Formula (1) is used to divide the wireless sensor network into units of equal length, continuous, but not intersecting [20]:

$$W'_{sppu} = \frac{S \pm \{P_{D1}, P_{D2}, \ldots, P_{Dn}\}}{A_{pi} * \{A_{p1}, A_{p2}, \ldots, A_{pi}\}} \pm \frac{A_{pi} * D_n}{n} \pm mean(c) \tag{1}$$

For any two units, the Euclidean distance between their data is calculated. Euclidean distance is a commonly used distance measurement method used to measure the similarity or difference between data [21]. Assuming that c_1 and c_2 represent any two data units present, Formula (2) is used to calculate the Euclidean distance between the data in any two units [22]:

$$\mathrm{dist}(c_1, c_2) = \frac{\{c_1, c_2\}\mathrm{near}(c)}{\{\mathrm{Density}\varepsilon_{c1}\} * \{\mathrm{Density}\varepsilon_{c2}\}} \otimes \eta_{c2} \tag{2}$$

$$R'_{spp} = \frac{Q'_{ASYY\delta} \pm \mathrm{Densityk}}{k''_{sdff} * u''_{dfkk}} \Longleftrightarrow E''_{sdpp} * o'_{asdd} \tag{3}$$

Cluster data units based on the calculated Euclidean distance. Clustering is the process of grouping similar data units, with the aim of finding data units with similar features and forming clustering clusters [23]. It is assumed that u''_{dfkk} represents the cell distribution adjustment function, and k''_{sdff} represents all non empty cell information. Densityk represents the average data cell distribution, and $Q'_{ASYY\delta}$ represents the given initial cell radius. Formula (3) is used to cluster its data cells.

According to the clustering results, data transmission efficiency rules are formulated. These rules can be based on distance, similarity, or other factors between data units to achieve efficient data transmission. For example, data units that are closer together can be divided into the same transmission group and data transmission can be prioritized. It is assumed that $r(D)_{xcjj}$ represents the initialization configuration message broadcasted by aggregation node D, and TS_{spp} represents the current timestamp. P'_{fh} represents the calculation of transmission delay based on timestamp, and g'_{dg} represents the remaining energy of the node. E'_{spp} represents node grouping identification, and k'_{faej} represents distance factor. Formula (4) is used to construct data transmission efficiency rules [24]:

$$P'_{wpp} = \frac{E'_{spp} * g'_{dg}}{P'_{fh}} * \frac{TS_{spp} * r(D)_{xcjj}}{k'_{faej}} \tag{4}$$

$$e'_{sf} = \frac{u''_{vn} \pm \eta'_{fg}}{P'_{wpp} * W'_{sppu}} * R'_{spp} \pm \mathrm{dist}(c_1, c_2) \tag{5}$$

According to the established data transmission efficiency rules, data transmission in wireless sensor networks is optimized, including selecting appropriate transmission paths, adjusting transmission time, optimizing transmission protocols, etc., to improve data transmission efficiency and performance. It is assumed that η'_{fg} represents the readings of all child nodes, and u''_{vn} represents the delay constraint specified by the aggregation node. Formula (5) is utilized to achieve data transmission efficiency in wireless sensor networks:

In Formula 5, c_1, c_2 are the any two data units; $dist(c_1, c_2)$ indicates that the received power of the terminal is inversely proportional to the distance from the transmitting end; e'_{sf} is the data transmission efficiency in wireless sensor networks.

In the process of wireless network connection and data transmission, device manufacturers need to take measures to protect the security and privacy of user data, including using encryption technology to protect the confidentiality of data transmission, and establishing secure authentication and authorization mechanisms to ensure that only authorized users can access and use data. It is also necessary to consider that sometimes wearable devices may not be able to connect to the network, such as when the network signal is weak or there is no network coverage. In this case, the device can have offline mode, which can store data on the device itself and synchronize during network recovery.

In summary, wearable intelligent devices based on wireless networks rely on wireless connection technology for network connection and data transmission. Device manufacturers need to consider factors such as wireless connectivity stability, data synchronization and cloud services, data security and privacy protection to provide a stable, secure, and convenient network connection and data transmission experience.

2.4. Energy, waterproofing and durability design

The energy management, waterproof performance, and durability design of wearable intelligent devices based on wireless networks need to consider the following aspects:

1) Energy management design: The energy consumption of devices is optimized, and low-power processors and electronic components are adopted to extend battery life. Through intelligent energy management algorithms, dynamic regulation of different functional modules of the device is achieved to improve energy utilization efficiency, provide energy-saving mode or sleep mode, and reduce energy consumption when the device is not in use. 2) Waterproof performance design: Waterproof materials and sealing structures are selected to protect the internal circuits of the equipment from moisture intrusion, and waterproof level testing is conducted to ensure the waterproof performance of the equipment at different water depths and times. Waterproof interfaces and slots are designed to ensure waterproof performance during charging and data transmission. 3) Durability design: The sturdy and durable shell material is used to resist daily drops, collisions, and wear. Tempered glass or scratch resistant coating is used to protect the display screen to reduce scratches and damages. Structural strength testing is conducted to ensure the durability of the equipment under various forces and pressures. Attention should be paid to the durability of the connecting components of the device (such as watch straps, buttons, etc.) to ensure that they can withstand the pulling and bearing forces of daily use. 4) Equipment sealing design: The interface and connection parts of the equipment need to have good sealing performance to prevent moisture, dust, and impurities from entering the interior of the equipment. Sealants and gaskets are used to ensure the sealing of various interfaces and buttons of the equipment. Sealing tests are conducted to ensure the sealing performance of the equipment in various environments. 5) High temperature and humidity resistance design: The equipment should have certain high temperature and humidity resistance performance to cope with high temperature and humidity environmental conditions. High temperature resistant materials and moisture-proof coatings are used to protect internal components of equipment from the effects of high temperature and humidity. High temperature and humidity tests are conducted to evaluate the performance stability of the equipment under different temperature and humidity conditions.

By comprehensively considering energy management, waterproof performance, and durability design, the stability and reliability of wearable intelligent devices based on wireless networks can be ensured under different environments and usage conditions. This design provides users with longer battery life, reliable waterproof performance, and a durable user experience.

2.5. User privacy protection design

When designing user privacy data protection for wearable smart devices, the following aspects can be considered and designed. Firstly, the device should minimize the collection and processing of users' personal data. Necessary information related to device functionality is only collected, and unrelated data collection is avoided [25,26]. In addition, the data shall be encrypted and processed with anonymization to ensure the protection of personal identity and sensitive information. The data storage shall adopt a secure mechanism, such as data encryption and access control, to prevent unauthorized access and data breach. Secondly, the device should give users clear authorization and selection rights, allowing them to decide whether to share personal data, as well as the purpose and recipient of the sharing. Users should be able to access and modify their personal data at any time, and have the right to ask the device manufacturer to delete or data anonymization their data. Finally, to protect user privacy data, devices should take necessary security measures, including the use of secure communication protocols and encryption technologies, to ensure the confidentiality and integrity of data during transmission and storage. Equipment manufacturers should also comply with applicable privacy laws and regulations, establish clear privacy policies, and establish internal data protection mechanisms to ensure compliance and accountability [27,28].

Through the principle of minimizing data collection and processing, ensuring user authorization and selection rights, as well as security and compliance measures, wearable intelligent devices can better protect user privacy data.

2.6. Specific equipment parameters - taking a smart watch as an example

The specific parameters of wearable intelligent devices based on wireless networks designed in this article are shown in Table 1.

3. Results and discussions

Test content.

a Material testing

Material testing often occurs during the prototyping phase. The paper take the following types of material testing:

Chemical testing: This involves detecting the presence of potentially irritating or harmful chemicals. These substances may be present in a part of a wearable device, which is strictly prohibited by local laws in various countries.

Mechanical/physical testing: This test ensures that all components in the equipment are properly connected to each other, especially for wear resistance.

Performance testing: This aspect of testing focuses on verifying that the equipment meets the quality standards set by the company, including whether the equipment is resistant to friction and pressure in extreme weather conditions.

b Hardware test

Wireless testing: Wireless testing involves speed, correctness/accuracy, and integrity of information transmitted over WiFi and Bluetooth.

Battery life cycle test: This test refers to the whole life of the battery from the time it is installed in the factory until it is fully discharged. It can test the battery in various modes of the device, such as airplane mode. Knowing and measuring the duration of the battery in the device is critical, because in industrial wearables, it generally cannot replace the battery.

Electrical safety testing: Since these devices are often in direct contact with the user's skin, the purpose of this test is to ensure that the user does not have any risk of electric shock or burn during use.

In this paper, STATA14.0 and EXCEL2007 are used to process the sampled data. This article took a smart watch as an example to conduct performance testing on wearable smart devices, with the first round testing the step counting function of the device. The test selected individuals with different height ranges of 0.8 m and above as the test subjects, divided into seven groups: 0.8–1 m, 1–1.2 m, 1.2–1.5 m, 1.5–1.65 m, 1.65–1.75 m, 1.75–1.85 m, and 1.85 m and above. Each group was subjected to 10 rounds of testing, totaling 70 rounds, to verify the accuracy of the equipment's step counting, as shown in Fig. 3.

Table 1
Various indices of wearable intelligent devices designed in this article.

Weight	44.5 g	Heart rate monitoring	Support
Watch size	46*42*11 mm	Artificial intelligence voice	Support
Refresh rate	60 Hz	NFC function	Support
Band length	140–210 mm	Mobile network	Support
Waterproof	100 m	APP data sharing	Support
Battery	Maximum 48 h		

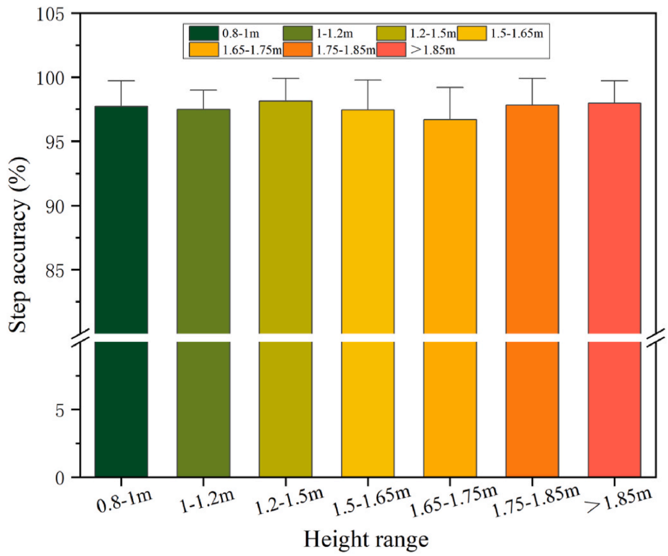

Fig. 3. Step counting accuracy for different height groups.

Among them, the horizontal axis represents different height ranges, and the vertical axis represents the accuracy of the device's step counting. The overall accuracy of the 1.2–1.5 m range was the highest, at 98.13 %. The overall accuracy between 1.65 and 1.75 m was the lowest, at 96.69 %. The overall step accuracy of all intervals was above 96.5 %, and the fluctuation did not exceed 3 %. It can be seen that the overall stability of the step counting function of the product is high and meets the needs of various height groups, and the product has a wide adaptability.

As the core function of wearable intelligent devices, the accuracy of health monitoring data is crucial. The heart rate test was conducted on individuals under different exercise states to determine the overall accuracy of the device's heart rate detection, as shown in Fig. 4.

Among them, the horizontal axis in Fig. 4a represents the distribution interval of heart rate accuracy, and the vertical axis represents the number of heart rate accuracy in this interval. The horizontal axis in Fig. 4b represents different exercise states, while the vertical axis represents the accuracy of heart rate. The test was divided into three groups: stationary state, mild exercise, and vigorous exercise, with each group conducting 20 tests. From Fig. 4a, it can be seen that the accuracy of heart rate measurement in a stationary state was basically above 96 %. Among them, the accuracy of three tests was above 99 %, and the accuracy of heart rate during exercise was basically distributed between 91 % and 96 %. There were 11 tests with accuracy ranging from 94 % to 95 % under mild exercise, and 14 tests with accuracy ranging from 91 % to 93 % under intense exercise. From Fig. 4b, it can be seen that the heart rate measurement accuracy in the stationary state was the highest, at 97.71 %, and the numerical fluctuation was relatively small. The difference in heart rate measurement accuracy between mild exercise and intense exercise was relatively small, with 94.46 % and 92.67 %, respectively. However, the measured values fluctuate significantly under intense motion. It can be seen that the overall heart rate measurement accuracy of the equipment is high, and the reliability of the equipment is guaranteed. Exercise has an impact on the accuracy of heart rate measurement, but the measurement error value is within a reasonable range.

In order to enhance the user experience of the device, different methods of data transmission have been considered in device design. Therefore, it is necessary to test the transmission effects of different transmission modes, as shown in Fig. 5.

Among them, the horizontal axis represents different tests. The left vertical axis indicates the transmission speed in megabytes per second,

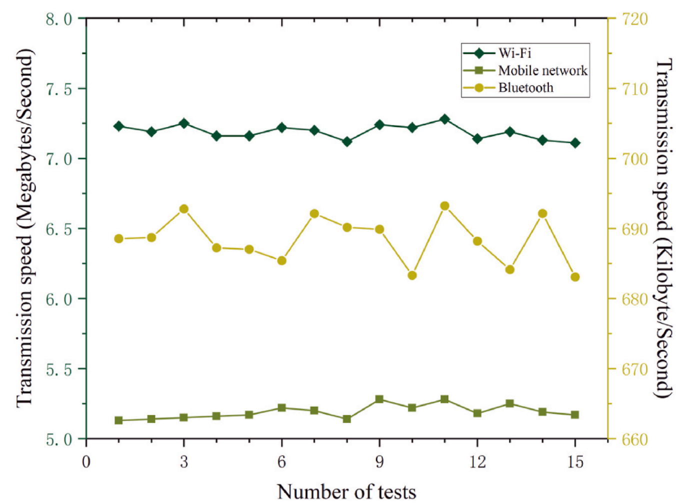

Fig. 5. Data transmission speed under different wireless connection methods.

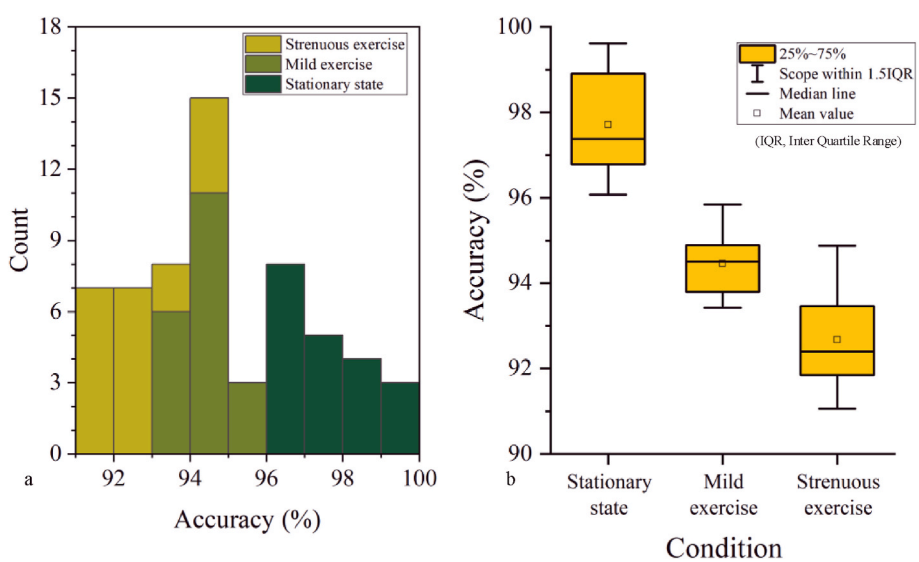

Fig. 4. Distribution range and accuracy of heart rate measurement under different exercise states.

and the right vertical axis indicates the transmission speed in Kilobyte per second. The test selected three transmission methods: Wi-Fi, mobile network, and Bluetooth, and each transmission method was tested 15 times. Among them, Wi-Fi had the fastest transmission speed with a test average of 7.19 Mb/s, followed by mobile networks with a test average of 5.19 Mb/s, and Bluetooth had the slowest transmission speed with a test average of 688.39 kB/s. As shown in Fig. 5, the fluctuation of transmission speed values measured multiple times is relatively small, indicating that the data transmission efficiency and stability of the device are relatively high.

Finally, the high-temperature environmental performance, low-temperature environmental performance, waterproof performance, and battery performance of the equipment were tested, as shown in Fig. 6.

Among them, the horizontal axis represents the number of tests, while the vertical axes a, b, c, and d respectively represent the high temperature environment performance rating index, low temperature environment performance rating index, waterproof performance rating index, and the battery life. High temperature environment performance test, low temperature environment performance test, and waterproof performance test are scoring tests, with a full score of 100 points, passing at least 60 points, moderate at least 70 points, good at 80 points, and excellent at 90 points. The battery test is to test the battery life of the device when fully charged and in normal use. Through testing, it can be seen that the overall performance score of the equipment in high temperature environments reached 94.12, and the overall performance score of the equipment in low temperature environments reached 86.97. The overall waterproof performance test score of the device reached 94, and the average battery life of the device reached 45.3 h.

In various tests of wearable smart devices, they have excellent performance, only lower than 90 points at low temperatures, more than 94 points in high temperature, waterproof tests, and a battery time of up to 45.3 h, which proves its excellent operability.

4. Conclusions

This article aimed to explore the industrial design of wearable intelligent devices based on wireless networks. Firstly, the industrial design of wearable intelligent devices based on wireless networks should focus on user experience and human-machine interaction. In the design process, consideration should be given to the comfort, ease of use, and personalized customization of the device to ensure that users can easily control the device and enjoy a comfortable wearing experience. Secondly, the industrial design of wearable intelligent devices based on wireless networks should focus on data security and privacy protection. These devices usually involve the collection and transmission of sensitive data such as personal health data and location information. Therefore, in the design process, strong security measures need to be taken to ensure that users' privacy is fully protected and prevent data breach and unauthorized access risks. Finally, the industrial design of wearable intelligent devices based on wireless networks should also focus on sustainability. In the process of material selection and manufacturing, renewable materials should be considered to reduce energy consumption and waste generation. The experiment found that the overall performance score of the equipment in the high temperature environment was 94.12, and the overall performance score of the equipment in the low temperature environment was 86.97. The overall waterproof performance test score of the device reached 94 points, and the average battery life of the device reached 45.3 h. All kinds of equipment performance is good, with excellent operability. The maintainability and upgradability of equipment should also be considered to extend the service life of equipment and reduce resource waste. Wearable intelligent devices based on wireless networks have broad application prospects in fields such as healthcare, sports and fitness, and

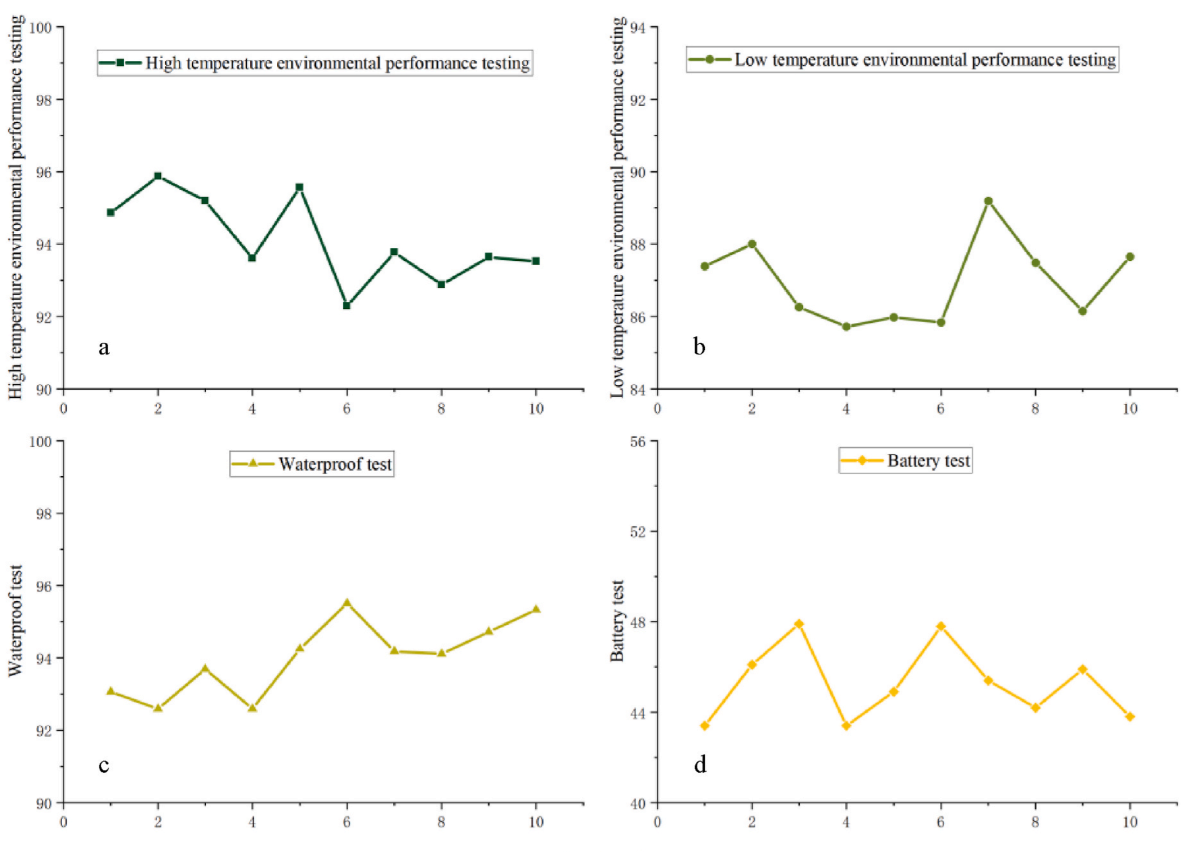

Fig. 6. Various tests of wearable intelligent devices.

smart homes. However, during the research process, there are still limitations in this article. Wireless network communication technology is relatively expensive compared to traditional wired network technology, and wearable devices need to continuously communicate with the network, which can lead to increased energy consumption and frequent charging. This article did not fully consider the environmental and economic aspects of the materials involved in the process. In future research, we will consider improving the availability of wearable devices based on wireless network technology from the perspective of wearable device materials, in order to further promote the development of wearable intelligent devices.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] Zhihan Lv, Alaa Halawani, Shengzhong Feng, Shafiq Ur Réhman, Haibo Li, Touch-less interactive augmented reality game on vision-based wearable device, Personal Ubiquitous Comput. 19 (3–4) (2015) 551–567.
[2] Karim Bayoumy, Mohammed Gaber, Abdallah Elshafeey, Omar Mhaimeed, H. Elizabeth, Dineen, A. Francoise, Marvel, et al., Smart wearable devices in cardiovascular care: where we are and how to move forward, Nat. Rev. Cardiol. 18 (8) (2021) 581–599.
[3] Jithin K. Sajeev, Anoop N. Koshy, Andrew W. Teh, Wearable devices for cardiac arrhythmia detection: a new contender? Intern. Med. J. 49 (5) (2019) 570–573.
[4] Zhu Wang, Zhiwen Yu, Bobo Zhao, Bin Guo, Chao Chen, Zhiyong Yu, EmotionSense: an adaptive emotion recognition system based on wearable smart devices, ACM Transactions on Computing for Healthcare 1 (4) (2020) 1–17.
[5] Apurva Adapa, Fiona Fui-Hoon Nah, Richard H. Hall, Keng Siau, Samuel N. Smith, Factors influencing the adoption of smart wearable devices, Int. J. Hum. Comput. Interact. 34 (5) (2018) 399–409.
[6] Xiaojun Zhang, Application of human motion recognition utilizing deep learning and smart wearable device in sports, International Journal of System Assurance Engineering and Management 12 (4) (2021) 835–843.
[7] Saad Khan, Simon Parkinson, Liam Grant, Na Liu, Stephen Mcguire, Biometric systems utilising health data from wearable devices: applications and future challenges in computer security, ACM Comput. Surv. 53 (4) (2020) 1–29.
[8] Zhipeng Song, Zhichao Cao, Zhenjiang Li, Jiliang Wang, Yunhao Liu, Inertial motion tracking on mobile and wearable devices: recent advancements and challenges, Tsinghua Sci. Technol. 26 (5) (2021) 692–705.
[9] Linda Taylor, Healthcare body sensor networks and smart wearable devices in Internet of Medical Things, American Journal of Medical Research 7 (1) (2020) 67–73.
[10] Furrukh Sana, Eric M. Isselbacher, Jagmeet P. Singh, E. Kevin Heist, Bhupesh Pathik, A. Antonis, Armoundas, Wearable devices for ambulatory cardiac monitoring: JACC state-of-the-art review, J. Am. Coll. Cardiol. 75 (13) (2020) 1582–1592.
[11] Liping Xie, Intelligent wearable devices based on nanomaterials and nanostructures for healthcare, Nanoscale 15 (2) (2023) 405–433.
[12] Yanxia Xu, Comparative study of a wearable intelligent sleep monitor and polysomnography monitor for the diagnosis of obstructive sleep apnea, Sleep Breath. 27 (1) (2023) 205–212.
[13] Hanbiba Sadia, Water environment monitoring system based on wireless sensor network, Academic Journal of Environmental Biology 2 (1) (2021) 39–47, https://doi.org/10.38007/AJEB.2021.020105.
[14] Ismail W.R. Taifa, Darshak A. Desai, Niravkumar Mukesh Bulsara, The development of an ergonomically designed product through an integrated product team approach, Int. J. Occup. Saf. Ergon. 27 (1) (2021) 160–178.
[15] R. Willink, An enhanced method for the evaluation of measurement uncertainty, Measurement: Sensors 24 (2022), 100373.
[16] R. Kalpana, Recurrent nonsymmetric deep auto encoder approach for network intrusion detection system, Measurement: Sensors 24 (2022), 100527.
[17] Hao Kong, Li Lu, Jiadi Yu, Yingying Chen, Feilong Tang, Continuous authentication through finger gesture interaction for smart homes using WiFi, IEEE Trans. Mobile Comput. 20 (11) (2020) 3148–3162.
[18] Lisa Graichen, Matthias Graichen, Josef F. Krems, Evaluation of gesture-based in-vehicle interaction: user experience and the potential to reduce driver distraction, Hum. Factors 61 (5) (2019) 774–792.
[19] Mohit Kumar, Priya Mukherjee, Kavita Verma, Sahil Verma, Danda B. Rawat, Improved deep convolutional neural network based malicious node detection and energy-efficient data transmission in wireless sensor networks, IEEE Transactions on Network Science and Engineering 9 (5) (2021) 3272–3281.
[20] Fumin Zhu, Chen Zhang, Zunxin Zheng, Farouk Ahmed, Practical network coding technologies and softwarization in wireless networks, IEEE Internet Things J. 8 (7) (2021) 5211–5218.
[21] Mohammad Javad Karimi, Alexandre Schmid, Catherine Dehollain, Wireless power and data transmission for implanted devices via inductive links: a systematic review, IEEE Sensor. J. 21 (6) (2021) 7145–7161.
[22] S. Muthu Mariappan, S. Selvakumar, A novel location pinpointed anti-jammer with knowledged estimated localizer for secured data transmission in mobile wireless sensor network, Wireless Pers. Commun. 118 (4) (2021) 2073–2094.
[23] Tanja Dorst, Maximilian Gruber, Benedikt Seeger, Anupam Prasad Vedurmudi, Tizian Schneider, Sascha Eichstadt, et al., Uncertainty-aware data pipeline of calibrated MEMS sensors used for machine learning, Measurement: Sensors 22 (2022), 100376.
[24] Achyut Shankar, K. Sumathi, Perumal Pandiaraja, Stephan Thompson, Xiaochun Cheng, Wireless multimedia sensor network QoS bottleneck alert mechanism based on fuzzy logic, J. Circ. Syst. Comput. 31 (11) (2022), 2250198, 1-2250198:18.
[25] Jian Chen, Shaojing Song, Yang Gu, Shanxin Zhang, A multisensor fusion algorithm of indoor localization using derivative Euclidean distance and the weighted extended Kalman filter, Sens. Rev. 42 (6) (2022) 669–681.
[26] Swathi Jamjala Narayanan, Cyril Joe Baby, Boominathan Perumal, Rajen B. Bhatt, Xiaochun Cheng, Muhammad Rukunuddin Ghalib, Achyut Shankar, Fuzzy decision trees embedded with evolutionary fuzzy clustering for locating users using wireless signal strength in an indoor environment, Int. J. Intell. Syst. 36 (8) (2021) 4280–4297.
[27] Nguyen Anh Tu, Thien Huynh-The, Kok-Seng Wong, M. Fatih Demirci, Young-Koo Lee, Toward efficient and intelligent video analytics with visual privacy protection for large-scale surveillance, J. Supercomput. 77 (12) (2021) 14374–14404.
[28] Bailing Liu, Paul A. Pavlou, Xiufeng Cheng, Achieving a balance between privacy protection and data collection: a field experimental examination of a theory-driven information technology solution, Inf. Syst. Res. 33 (1) (2022) 203–223.