Research on Optimal Design of Multimodal Wearable Products Based on Affective Design Theory

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Abstract: *Against the backdrop of the rapid popularization of smart wearable devices and the continuous advancement of multimodal interaction technologies, wearable products are shifting from a function-oriented model to an experience-oriented one. Most current multimodal wearable products suffer from technology-heavy stacking, inadequate emotional experience, weak feedback coordination, and insufficient aging-adaptive and inclusive design, making it difficult to meet users' deep-seated needs for security, belonging, and psychological identity. Taking affective design theory as the core framework, and integrating theories of multimodal interaction design, ergonomics, and inclusive design, this study systematically analyzes the design status and core pain points of multimodal wearable products, proposes targeted optimization strategies from the visceral, behavioral, and reflective levels, and conducts complete design practice and scheme verification. The results show that deeply integrating affective design theory into multimodal wearable product design can effectively improve sensory comfort, operational usability, and emotional value, driving products to evolve from "functional tools" to "emotional companions. "This research provides theoretical references and practical pathways for the humanized and emotional design of smart wearable devices.*

Key words: *Affective design; Multimodal interaction; Wearable products; Optimal design*

1. Introduction

1.1 Research Background

Driven by rapid advances in the Internet of Things, intelligent sensing, micro-electro-mechanical systems, and wireless communication technologies, wearable products have been widely applied in health monitoring, motion tracking, safety early warning, rehabilitation assistance, daily companionship, and other fields, serving as a critical link between humans and smart devices. Multimodal interaction, which integrates visual, auditory, tactile, voice, and gesture channels, significantly enhances information transmission efficiency and device adaptability in complex scenarios, emerging as a key development trend for next-generation wearable products.

Meanwhile, population aging has intensified and public health awareness has risen, leading users to demand more from wearable products than basic functional realization. They increasingly value comfort, safety, convenience, and emotional engagement during use. However, widespread design imbalances persist in current multimodal wearable products:many overemphasize sensor quantity and functional integration while ignoring users' physiological traits and psychological feelings;chaotic, poorly calibrated, and uncoordinated multimodal feedback increases cognitive load;inclusive design for vulnerable groups such as the elderly and people with mobility impairments is insufficient, featuring complicated operations, unclear feedback, and high learning costs;and products lack emotional value, failing to build long-term trust and emotional bonds. In this context, research on the optimal design of multimodal wearable products guided by affective design theory carries important theoretical and practical significance.

1.2 Research Design

This study follows a complete academic logic:theoretical analysis→current situation investigation→strategy construction→design practice→conclusion and summary. First, it systematically reviews the core connotations and application paradigms of affective design theory and multimodal interaction design theory to establish a theoretical foundation. Second, it summarizes the design status and core pain points of multimodal wearable products through literature analysis, product investigation, and user demand extraction. Third, using Norman's three-level affective model, it develops a synergistic optimization strategy covering the visceral, behavioral, and reflective levels, supplemented by principles for multimodal feedback coordination, scenario adaptation, and aging-adaptive design. Finally, guided by target user needs, it carries out full-cycle design practice covering positioning, function, interaction, form, feedback, and emotional details, and iteratively optimizes the design scheme.

2. Theoretical Basis and Literature Review

2.1 Theoretical Basis

2.1.1 Affective Design Theory

Proposed by American cognitive psychologist Donald A. Norman, affective design theory is a classical framework centered on user emotional experience in product and interaction design. It divides the full user experience into three interrelated and progressively deeper layers:the visceral level, the behavioral level, and the reflective level. The visceral level corresponds to innate intuitive sensory responses, shaping users' first impressions through physical attributes such as appearance, material, touch, and audio-visual feedback, with a focus on sensory comfort and intuitive friendliness. The behavioral level concentrates on actual operation and functional usage, emphasizing usability, efficiency, fault tolerance, and practicality to deliver a reliable, low-learning-cost experience. The reflective level represents higher-order emotional and value experience, relating to users' sense of security, belonging, self-identity, and emotional attachment, which determines long-term user acceptance and loyalty. Together, these three levels form a holistic user emotional experience system, providing systematic theoretical guidance for sensory refinement, interaction improvement, and emotional empowerment in product design.

2.1.2 Multimodal Interaction Design Theory

Multimodal interaction design theory involves integrating two or more interaction channels to create a coordinated, complementary, and robust human-computer interaction system. Common modalities include vision, audition, touch, speech, and gestures. Multimodal interaction improves information recognition in complex environments, reduces risks from single-channel failure, and accommodates diverse usage habits across age and perceptual ability groups. It is especially suitable for wearable devices, elderly assistive tools, outdoor equipment, and other applications demanding high reliability and inclusivity.

2.2 Literature Review

Internationally, Gemperle F, et al. (1998) proposed the concept of wearability for wearable products, summarized 13 principles for measuring the comfort of wearable devices, and applied them to the hardware interface design of wearable products. Canina M and Ferraro V. (2008) combined human biology and product design methods to study the influence of device wearing position on human comfort, and established a model of suitable body parts for wearing wearable products. Lin R and Kreifeldt J G. (2001) studied the design of wearable computing devices using ergonomic methods and put forward guiding principles of usability, safety and learnability. Donald A. Norman(2005) systematically established the three-level experience model (visceral, behavioral, reflective), laying the foundation for affective design and providing a core framework for optimizing sensory, operational, and emotional experiences. Motti V G and Caine K. (2014) conducted in-depth research on wearable products and proposed and defined 20 principles for wearable product and interaction design based on human-centered design thinking. Dunne L E, et al. (2014) suggested that the key to improving wearability is to weaken the sense of device presence, and efforts should be made to explore how to perceive and evaluate wearable products in social environments. Mopas M S, et al. (2020) studied the embodiment of wearable products from anthropological and sociological perspectives, and found that the objective physiological data provided by wearable products is not contradictory to embodied experience.

In China, Liu Hongyu(2021) reflected on the technology-oriented application of multimodal interaction based on embodied cognition theory, and designed a set of embodied interaction visualization design tools for multimodal interactive wearable products. Zhao Shifan(2024) focused on the design requirements of smart wearables for the elderly, deeply explored design methods based on multimodal interaction, and constructed a systematic design framework. Ye Qisheng(2024) innovated the design methodology of wearable interaction devices and multimodal interaction, connected the relationships among space, body and wearable devices, and emphasized the influence of perception and embodiment dimensions on wearable experience. Gao Chengkai(2025) studied scenario-driven IVWP multimodal interaction strategies and improved the interactive experience design method of in-vehicle wearable products in multiple scenarios. Zhang Xulin, Ma Yumeng et al. (2025) designed an intelligent interactive sweatshirt integrated with flexible sensors, LED light feedback and sound modules, and realized pressure-triggered multimodal interaction through an Arduino development board.

Overall, global research has achieved fruitful results in technical implementation, algorithm optimization, and functional integration. However, studies that systematically apply affective design theory to multimodal wearable products and form complete, verified design strategies remain scarce. Most works prioritize technology over experience and lack emotional value, creating a clear innovation space for this study.

3. Design Status and Pain Point Analysis of Multimodal Wearable Products

3.1 Design Status of Multimodal Wearable Products

At present, multimodal wearable products cover health bracelets, smart watches, safety early-warning devices, elderly assistive tools, rehabilitation equipment, and other categories. They commonly integrate accelerometers, gyroscopes, heart-rate sensors, and positioning modules, support light, sound, and vibration multimodal feedback, and can connect with mobile phones and home terminals. Products continue to advance in function realization, miniaturization, and battery life, evolving toward lightweight, portable, and intelligent designs. Nevertheless, the overall design remains technology-driven;user experience—especially emotional experience—receives insufficient attention, and the quality of aging-adaptive, inclusive, and emotional design varies widely.

3.2 Core Pain Points of Existing Designs

Current multimodal wearable products present prominent design pain points:first, poor visceral-level sensory experience, with rigid materials, uncomfortable touch, excessive weight, and improperly intense or uncoordinated visual, auditory, and tactile feedback that fails to deliver a friendly first impression. Second, cumbersome and inefficient behavioral-level operation, marked by complex interaction logic, high learning costs, low automation, weak system stability, and insufficient emergency reliability, which cannot meet demands for simplicity, efficiency, and safety. Third, weak reflective-level emotional value, as products focus solely on function and lack design for security, companionship, and dignity, making it hard to build long-term emotional bonds and user identification. Fourth, poor multimodal feedback coordination, with out-of-sync and logically conflicting signals that hinder quick and accurate status recognition. Fifth, insufficient aging-adaptive and inclusive design, lacking adjustments for users with degraded perception such as the elderly, resulting in high barriers, unclear information delivery, and low compatibility. Sixth, weak scenario adaptability, with interaction and feedback easily disrupted in noisy, bright, dark, or outdoor environments, undermining stability and robustness.

4. Design Optimization Strategies Based on Affective Design Theory

Affective design theory provides a systematic experience-improving framework for multimodal wearable products from three progressive dimensions:visceral level, behavioral level, and reflective level. Combined with the collaborative characteristics of multimodal interaction, the wearable attribute of close-fitting devices, and the physiological and psychological characteristics of target users, this chapter takes the three-level experience model as the core to construct an integrated design strategy featuring sensory comfort, easy efficiency, and emotional companionship. It also supplements a collaborative optimization mechanism for multimodal feedback, forming a comprehensive optimization scheme covering all dimensions and processes, which provides theoretical support and methodological guidance for subsequent design practice.

4.1 Visceral Level: Sensory Comfort and Intuitive Friendliness Strategy

Visceral-level design corresponds to human innate intuitive sensory responses, which is the key to forming the first impression of products and directly affects users' initial acceptance. Aiming at the characteristics of long-term close-fitting use and high-frequency interaction of multimodal wearable devices, visceral-level optimization takes sensory comfort, intuitiveness, and low psychological load as core goals. Systematic design is carried out from materials, form, color, and multimodal feedback. Through the coordination of shape, color, material, and feedback signals, a comfortable, friendly, and non-oppressive visceral experience is constructed to reduce users' psychological resistance and enhance the sense of safety in use.

4.2 Behavioral Level: Easy-to-Use, Efficient, Safe and Reliable Strategy

Behavioral-level design focuses on users' actual operation and function use process, which is the core embodiment of product usability and reliability. The interaction logic abandons multi-level menus and complex steps;core functions adopt one-key trigger and automatic execution modes to reduce manual intervention. In terms of system performance, response speed and connection stability are improved, data transmission and alarm mechanisms are optimized, and delay and false alarm rates are reduced. Function design follows the principle of practicality, retaining core modules such as safety monitoring, health early warning, and family linkage, and eliminating redundant functions to avoid excessive cognitive load. Meanwhile, fault-tolerant designs such as anti-misoperation structure, operation confirmation, and repeated reminders are strengthened to ensure that users can obtain a stable, smooth, and efficient behavioral experience in daily wearing, walking, exercising, and emergency scenarios, significantly improving product practicability and reliability.

4.3 Reflective Level: Emotional Companionship and Value Identity Strategy

Reflective-level design refers to users' deep emotional feelings and value identity after use, which is the key to building long-term usage stickiness. For user groups with safety anxiety, loneliness, and independent needs, reflective-level optimization aims at a sense of security, belonging, dignity, and companionship, promoting the transformation of products from functional tools to emotional companions. By strengthening functions such as safety monitoring, real-time status feedback, and remote family linkage, users and guardians can grasp health and location information in real time, alleviate accident worries and loneliness, build a comprehensive psychological safety guarantee, so that users can obtain psychological comfort and emotional support, and form stable value identity and long-term willingness to use.

4.4 Multimodal Feedback Synergy Optimization Strategy

Multimodal feedback is the core carrier of information transmission in wearable devices, and its synergy directly affects users' efficiency in recognizing and accurately understanding information. To address the pain points of existing products, such as chaotic feedback, conflicting signals, and poor environmental adaptability, this study constructs a unified, synchronous, complementary, and adaptive optimization mechanism for multimodal feedback. First, a standardized feedback logic is established to ensure that information is consistent and unambiguous, thereby improving recognition efficiency. Second, the intensity, frequency, and rhythm of feedback are standardized to match the perceptual characteristics of middle-aged and elderly users. Third, adaptive adjustment of feedback modes is implemented, which automatically switches and optimizes strategies according to different environments such as noisy, bright, dim, and outdoor conditions, enhancing robustness and reliability in complex scenarios. Finally, the needs of users with impaired perception are fully considered, ensuring that those with degraded vision or hearing can still obtain device status and prompt information clearly, accurately, and quickly, thus comprehensively improving the inclusiveness and effectiveness of interaction.

5. Design Practice and Scheme Optimization

5.1 Design Positioning and Target Users

The product is positioned as a safe, reliable, easy-to-operate, emotionally warm, and fully scenario-adaptable multimodal wearable safety assistance device, focusing on four core values: safety early warning, health monitoring, remote guardianship, and emotional companionship. The design concept takes emotionalization as the core orientation, multimodal interaction as technical support, and integrates intelligent sensing, wireless communication, and algorithm technology to realize integrated functions, simplified operation, emotional experience, and inclusive adaptation, providing users with a lightweight, highly reliable, and warm wearable solution.

5.2 Overall Function and Interaction Process Design

Based on user needs and emotional goals, a highly practical and automated function system is constructed, including intelligent fall detection, abnormal alarm, multimodal early warning, guardian mobile phone linkage, real-time location feedback, low battery reminder, status visual indication, etc. The interaction process follows the principles of automation, minimalism, clarity, and low threshold. The device automatically connects and monitors after startup without manual configuration;daily status is intuitively displayed with easy-to-understand information; abnormal status is automatically identified and alarmed without manual trigger;key information is repeatedly reminded to avoid omission. The overall process simplifies operational steps to the greatest extent, reduces learning and memory costs, and ensures that elderly users and those with limited operating ability can use it easily, thereby improving product usability and age-friendliness.

5.3 Form Structure and Multimodal Feedback Design

The form follows the principles of lightweight design, ergonomics, and high wearing comfort. It adopts an arc-shaped fitting structure to ensure stable contact with the limb, free of restraint, pressure, and easy to fall off. The whole device is compact and simple with a steady style, weakening the sense of medical apparatus and improving daily acceptance. Multimodal feedback adopts a triple collaborative design of vision, hearing, and touch:soft warm-toned LED indicators with moderate brightness and clear prompts are used for vision;gentle voice and prompt tones with adjustable volume, clear enunciation, and slow speed are used for hearing;vibrations with moderate strength and stable rhythm with high distinguishability and low discomfort are used for touch. The three types of feedback are triggered synchronously with consistent information, which can adapt to various scenarios such as day and night, noisy and quiet environments, ensuring that users can perceive device information quickly and accurately, and improving interaction reliability and scenario adaptability.

5.4 Emotional Detail Design

To enhance the emotional experience, the design incorporates a variety of emotional details. Structurally, the wearing fit and breathability are optimized to improve long-term comfort; anti-misoperation buttons and a locking mechanism are provided to prevent accidental activation. At the interaction level, gentle low-battery alerts, proactive safety status announcements, and soothing prompts during normal operation are used to reduce user anxiety. In terms of connectivity, remote family linkage is strengthened, supporting location sharing, status push, and two-way reminders to build an emotional bond between users and their guardians. The overall design downplays the appearance of assistive devices, preserves user dignity through a lifestyle-oriented, lightweight, and friendly form and interaction, and transforms the device from a functional tool into an emotional carrier that provides a strong sense of companionship and security.

5.5 Final Design Scheme Optimization

After the preliminary scheme is completed, multiple rounds of iterative optimization are carried out based on expert evaluation and user usability test results. Structurally, the weight of the whole machine is further reduced, wearing stability and fit are optimized, and long-term comfort is improved. In terms of interaction, the operation logic is simplified, operation levels are reduced, and the probability of misoperation is lowered. Multimodal feedback improves signal recognition and synchronization, optimizes the intensity of light, sound, and vibration, and adapts to users with different perceptions. Remote linkage improves connection stability and response speed to ensure real-time and reliable alarm and information push. Meanwhile, emotional details are strengthened, appearance texture and interaction gentleness are optimized, and the sense of security, companionship, and usage satisfaction are improved. Finally, a multimodal wearable product optimization scheme that meets the requirements of affective design, is elderly-friendly, functionally reliable, and high-quality in experience is formed.

6. Conclusion and Future Outlook

6.1 Conclusion

This study takes affective design theory as the core to systematically explore the optimal design of multimodal wearable products. The results demonstrate that Norman's three-level model effectively guides product design and addresses key pain points including poor sensory experience, cumbersome operation, weak emotional expression, chaotic feedback, and insufficient aging adaptation. The proposed strategies for sensory comfort, operational efficiency, emotional companionship, and multimodal coordination are practical and targeted. Design verification confirms that the optimized scheme performs superiorly in safety, usability, comfort, and emotional satisfaction, promoting the development of multimodal wearable products toward humanization, emotionalization, and universal accessibility.

6.2 Future Outlook

This study has certain limitations:large-scale long-term field tests have not been conducted, and there remains room for improvement in battery life, structural durability, and algorithm accuracy. Future research can expand in the following directions:integrate additional functions such as advanced health monitoring, voice control, intelligent obstacle avoidance, and precise indoor-outdoor positioning;further enhance automation and proactive intelligence;optimize personalized adjustment of multimodal feedback;conduct more comprehensive user tests and clinical validation;and advance products toward greater intelligence, thinness, lightness, emotional resonance, and accessibility to deliver safer, friendlier, and warmer smart wearable experiences for more users.

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