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

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Abstract: *With the development of intelligent wearable devices and all sorts of interaction technology, people now want wearables that can do more than just offer functions; they also want good experiences. Most of the current multimodal wearable products focus too much on technology and lack emotion; they have poor feedback coordination, fail to meet the needs of older people, are not inclusive, and thus do not meet people's basic demands for security, a sense of belonging and psychological identity. Based on the theory of affect design and in conjunction with the theories of multimodal interaction design, ergonomics and inclusive design, this paper will investigate the current design conditions and main problems of multimodal wearable products, propose targeted optimisation plans at the visceral, behavioural and reflective levels, and carry out full design practice and scheme verification. Based on the above results, it can be concluded that applying the theory of affective design in the development of multimodal wearable products can improve their sensory comfort, operational usability and emotional appeal; thus, they can be changed from "functional tools" to "emotional companions". The above provide a theoretical basis and some practical ideas for the humanised and emotional Design of intelligent wearable devices.*

Keywords: *Affective Design, Multimodal Interaction, Wearable Products, Optimal Design*

1. Introduction

1.1 Research Background

With the rapid development of the Internet of Things, intelligent sensing, micro-electro-mechanical systems and wireless communication technology, wearable products have been used in many places for health monitoring, motion tracking, safety early warning, rehabilitation assistance, daily life, etc., and are now indispensable links connecting people and smart devices. Multimodal interaction is the combination of many kinds of sensory information, such as sight, sound, touch, voice and movement, to improve the efficiency of communication and expand the application scope of devices in daily life.

At the same time, as the population is ageing and public health consciousness has grown, more people have started to demand wearable devices. Recently, more and more people have started paying some attention to their own lives and emotions. Many of the Design Imbalance problems in the current generation of multimodal wearable products still exist: too much focus has been placed on the number of sensors and functional integration, there has been no regard for the physiological and psychological conditions of users, chaotic and poorly calibrated multimodal feedback increases cognitive load, inclusive Design for vulnerable groups, such as older adults and people with mobility impairments, is lacking, and the products do not have emotional value or long-lasting trust. Based on the above, research will be conducted to find the best Design for multimodal wearable products in accordance with Affective Design Theory.

1.2 Research Design

The above is the outline of this paper, which will be introduced. First, to offer a theoretical basis, this paper will systematically introduce the main ideas and application cases of Affective Design Theory and Multimodal Interaction Design Theory. Second, based on the analysis of literature, product research and user demand collection, summarize the design progress and main problems of multimodal wearable products. Thirdly, in accordance with Norman's three-level model of emotion, we will jointly promote the visceral, behavioural and cognitive levels, set rules for coordinating multimodal feedback, design scenarios and create them for older people. Finally, in line with the needs of the target users, full-cycle design practice will be carried out that covers positioning, function, interaction, form, feedback and emotion, and the Design Plan will be iteratively improved.

2. Theoretical Foundation and Literature Review

2.1 Theoretical Foundation

2.1.1 Affective Design Theory

Proposed by American cognitive psychologist Donald A. Norman's theory of affect is one of the first systems to study emotions in product and interaction design. The three links in the whole user experience, from shallowest to deepest, are the felt experience, the shown behaviour and the conscious thought. Visceral sense is a person's first, unconscious intuition of something based on basic feelings and experiences; it is related to sensory pleasure and often connected with one's first impression of an object or person. Behavioural level refers to the actual operation and functional use of a system, so it should be simple to operate and efficient in terms of fault tolerance. A high degree of reflection shows that a person has had deep emotional and value experiences; it can foster a sense of security, belonging, self-identity, emotional attachment, etc., and thus motivate long-term acceptance and loyalty. Together, the three levels constitute a whole system of user emotions and can offer full theoretical support for sensory refinement, enhancement of interaction and emotional empowerment in product design.

2.1.2 Multimodal Interaction Design Theory

The Aim of Multimodal Interaction Design Theory is to combine two or more types of interaction to create a good and effective system for people and computers. The above are the five senses and expression methods. Multi-modal interaction can help to recognise information in complex environments and avoid the problem of single-channel failure; it can meet the different needs of people of all ages and those with various visual impairments. Wearable devices, products for the care of older people, outdoor equipment and other places with high reliability and inclusivity can all be used for this purpose.

2.2 Literature Review

Gemperle F and others (1998) have put forward the concept of wearability for wearable products around the world, listed 13 indicators to assess the comfort of wearable devices, and applied them to the hardware interface design of wearable products. Canina M and Ferraro V. (2008) have combined the method of human biology with product design to study how the location of a device affects people's comfort and have built a model for suitable body areas to wear wearable products. Lin R and Kreifeldt JG (2001) have conducted ergonomic research on the design of wearable computers and put forward general rules for usability, safety and learnability. Donald A. Norman (2005) put forward that the three levels of experience are visceral, behavioural and reflective; thus, he provided a foundation for affective design and an all-encompassing way to improve sensory, operational and emotional experiences. Motti V G and Caine K. (2014) have conducted many studies on wearable products and put forward and defined 20 principles for wearable product and interaction design based on human-centred design thinking. Dunne LE and others (2014) proposed that the main way to improve wearability is to reduce the sense of device presence, so research should focus on how people perceive and judge wearable products in social situations. Mopas M S and others (2020) have studied the embodiment of wearable products from the perspectives of anthropology and sociology and found that the objective physiological data obtained by wearable products do not conflict with embodied experience.

Liu Hongyu (2021) has studied the application of technology in multimodal interaction based on the theory of embodied cognition and developed a set of design tools for visualisation of embodied interaction in multimodal interactive wearable products. Zhao Shifan (2024) has conducted research on the Design Requirements for Smart Wearables for Older Adults, explored various Design Methods based on Multimodal Interaction in detail, and proposed an organised Design Framework. Ye Qisheng (2024) has put forward new Design Methods for wearable interaction devices and multimodal interaction, established the link among space, body and wearable devices, and pointed out the influence of perception and embodiment on the experience of wearables. Gao Chengkai (2025) has been conducting research on scenario-based IVWP multimodal interaction strategies and has also improved the method for interactive experience design of in-vehicle wearable products in all kinds of environments. Zhang Xulin, Ma Yumeng and others (2025) have developed an intelligent, interactive sweatshirt that can sense all kinds of changes in pressure through sensors and flexibly respond by means of LEDs, sound modules, etc.

Most of the problems mentioned above have been solved by many research groups around the world. No one has systematically applied the theory of affective design to multimodal wearable products and provided a full set of verified Design Strategies. Most works focus on technology and do not show emotion; thus, this study will make a new contribution.

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

3.1 Design Status of Multimodal Wearable Products

Many kinds of multimodal wearable products are available at present, such as health bracelets, smartwatches, safety early-warning devices, elderly assistance tools, rehabilitation equipment, etc. Generally speaking, they have accelerometers, gyroscopes, heart rate sensors and location modules; they support all kinds of light, sound and vibration feedback; and they are compatible with mobile phones and home appliances. The functions of the products continue to be improved, and they are getting smaller, lighter, more energy-efficient, portable and intelligent. The general Design is still technology-driven, and to some extent, the experience and emotions of the users have been overlooked.

3.2 Main Problems in the Current Design

There are still some Design Problems in the current multimodal wearable products. First of all, there is a lack of deep sensory perception; stiff materials, uncomfortable contact, excessive weight, and inappropriate intensity or uncoordinated visual, auditory and tactile feedback will not make a good first impression. Secondly, there are many problems at the level of behaviour: the interaction logic is complex; the learning cost is too high; automation is weak; the system has poor stability; and emergency reliability is insufficient. Thirdly, there is a weak sense of emotional value; the products only have functions and do not provide security, companionship and dignity, so they are unable to form a long-term emotional bond with users or win their trust. Fourth, the various feedback channels are not coordinated, and some of the information is old or illogical. Fifth, there is a lack of ageing-in-place and inclusivity; people with declining senses, such as older adults, find it difficult to operate and cannot understand the information. Sixth, it is relatively sensitive to the environment and will be easily damaged by noise, light, shade, changes in weather, etc.; it is neither stable nor durable.

4. Design Optimisation Strategies Based on Affective Design Theory

Based on the theory of affective design, the feeling of wearing a wearable device on one's body, one's behaviour and emotions in relation to it should all be improved. Cooperative interaction refers to the cooperation of all kinds of things, and such devices are generally for people with special physiological and psychological needs. Therefore, based on the above, the three-level experience model in this chapter will be used to present the whole Design Plan for sensory comfort, ease of use and emotional support. Based on the above, all kinds of feedback will be collected to form a comprehensive improvement plan that covers all aspects at any time, and theoretical support and methodological suggestions for the design work to be carried out next can also be provided.

4.1 Visceral Level: Sensory Comfort and Intuitive Friendliness Strategy

Visceral-level Design refers to people's basic and intuitive sense perception, and it is the first impression a product gives that directly affects how much people like it initially. As they are relatively long-lasting and frequently used, the main goals of optimisation at the visceral level are to increase the sense of comfort, strengthen intuition and reduce psychological stress. Systematic Design of Materials, Form, Colour and Multimodal Feedback is carried out. The coordinates, colours and materials of the shape should be pleasant and gentle so as not to cause stress for the users; thus, they will feel more relaxed and safe when using it.

4.2 Behavioural Level: Easy-to-use, convenient, safe, and reliable strategy

Behavioural-level Design considers how people will actually use the product and aims to achieve good usability and reliability in this regard. There is only one level or step in the interaction logic; it is triggered by pressing a single key and then runs automatically. The system should have good performance, be stable in operation, transmit data and alarms accurately, have a low rate of delay and false alarms. Some of the functions have been used, and only those necessary for the purpose of safety supervision, early warning of health problems and family support have been added to reduce mental stress. At the same time, fault-tolerant Design will also be employed to ensure that users can live normally and exercise comfortably in their daily lives, walk, etc.; in the event of a power failure or other problems, the product will still be usable.

4.3 Reflection Level: Emotional Companionship and Value Identification Strategy

Reflective-level Design refers to a person's deep emotions and values of identity after using a product; this may motivate them to use the product again and again. For groups of anxious users who are lonely and long for freedom, the aim of reflective-level optimisation is to provide a sense of security, belonging, self-worth and company; that is to say, it should be an emotional confidant rather than just a practical tool. Expand the function of safety monitoring to issue early warnings about changes in people's health and locations to all users and guardians so that they can be aware of potential accidents and loneliness in advance, build a complete psychological safety net, receive emotional support and help, establish a stable sense of self-worth, and continue to use the service for a longer time.

4.4 Multimodal Feedback Synergy Optimization Strategy

Most of the information in wearable devices is in the form of several modes, and it can help people learn about them better. The problems of the current products are that the feedback is unorganised, the signals are inconsistent, and it cannot respond to changes in the environment; thus, this paper proposes a unified, synchronous, complementary and adaptive optimisation mechanism for multimodal feedback. First, a standardised feedback logic should be established so that the information is uniform and easy to understand. Second, based on how middle-aged and older adults feel about it, we will change the intensity, duration and speed of the feedback. Thirdly, there is automatic adjustment of feedback modes; according to the conditions in different places, it will change or optimise the strategy, such as reducing the brightness of lights indoors when it is noisy and bright outside to improve robustness and reliability in complex environments. Finally, the needs of users with impaired perception have also been met; that is to say, people who are visually or hearing-impaired can still obtain clear and timely status and prompt information about the device, improving the overall inclusivity and operational efficiency of the product.

5. Design Practice and Scheme Optimisation

5.1 Design Position and Target Users

A good and safe all-weather wearable safety assistant that is simple to operate, has good emotional support, knows the circumstances well, and has the following four functions: early warning of danger, health monitoring, remote care and emotional support. According to the design concept of emotionalisation, multimodal interaction, intelligent sensing, wireless communication and algorithm technology, it can have all sorts of functions, be simple to operate, provide emotional experiences, offer all-encompassing adaptation, and be a lightweight, highly reliable and warm wearable product for users.

5.2 General Function and Interaction Process Design

Based on the needs and wishes of the users, many very practical and convenient functions have been added, such as intelligent fall detection, abnormal alarm, multi-channel early warning, guardian mobile phone notification, real-time location feedback, low-battery alerts, status display, etc. The process of interaction should be automatic, simple, clear and have a low threshold. The device will start up, connect and monitor automatically; it will show the daily status in an easy-to-understand manner; if there are any problems, an alarm will be sounded immediately; and important information will be repeatedly announced so that it is not missed. The whole process has been simplified to reduce the need for learning and memory; it is easy for older people and those with weaker bodies to operate, so it has increased convenience and age-friendliness.

5.3 Form Structure and Multimodal Feedback Design

It should be light in weight, have good ergonomics, and be comfortable to wear. It has an arc shape and can be worn around the limb; it is not too tight or high-pressure, and it will not easily fall off. The entire device is small and simple, so it is not complicated, and thus more people will be able to use it daily. Multimodal feedback is the combination of sight, sound and touch; for sight, soft, warm-toned LEDs of medium brightness and clear prompts are used; for hearing, gentle voices and prompt tones with adjustable volume, clear enunciation and slow speed are employed; for touch, vibrations of moderate strength and a stable rhythm, high distinguishability and low discomfort are used. All kinds of feedback will be continuously collected, and at any time and in any place, whether it is noisy or quiet, day or night, we will promptly and accurately obtain information about problems with the device to improve its operational stability and adaptability in different environments.

5.4 Emotional Detail Design

Many emotions can be added to the Design to make people feel good. It is soft, has good breathability for a long time, and also has anti-mistrigger buttons and a lock to prevent accidental operation. The low-battery warning will be light; otherwise, there will be no alarm and the system will continue to work normally. Add functions to share locations, post updates on conditions, send and receive messages, etc., to help older adults and their families stay in touch and reduce loneliness. In general, the purpose is to reduce the attention-grabbing effect of help devices, protect the sense of self-worth of older people by making them light and simple in appearance and operation, and change the functional thinking model of these devices into an emotion-focused system that can provide psychological support, comfort and security.

5.5 Final Design Scheme Optimisation

The first plan has been prepared, and based on the other comments from experts and users, it will be revised several times. The weight of the whole machine will be reduced further, stability and fit will be optimised, and long-term comfort will be improved. Reduce the volume of operation logic, decrease the number of operation levels, and thus lower the probability of errors. Multimodal feedback can help to recognise and coordinate all kinds of signals more effectively, change the intensity of light, sound and vibration, etc., according to the different sensory abilities of people. Remote Linkage will strengthen the link and improve the speed of distribution for alarms and other information. At the same time, strengthen the sense of emotion, refine the textures of the appearance and interaction, and increase the feelings of safety, companionship and usability. Finally, a plan to improve the multi-modal wearable product in accordance with the needs of affective design for older adults has been developed to ensure reliable operation and provide a good life experience.

6. Conclusion and Future Outlook

6.1 Conclusion

According to the theory of affective design, this paper will explore how to design good multi-modal wearable products. Therefore, Norman's three-level model can be employed to solve the problems of a lack of sensory pleasure, inconvenient operation, weak emotional response, chaotic feedback and failure to adapt with age in product design. All of the above suggestions for sensory comfort, operational efficiency, emotional support and multi-modal coordination are feasible and practical. Design verification has found that the optimised plan is better in terms of safety, usability, comfort and emotional satisfaction; thus, it will achieve the goal of humanising, emotionalising and universalising multimodal wearable products.

6.2 Future Outlook

There are some defects in this study; it does not have an extended long-term field test, and no improvements have been made to the battery life, structural durability and algorithm accuracy. In the future, many more functions will be added to the research, such as advanced health monitoring, voice control, intelligent obstacle avoidance, precise indoor-outdoor positioning, automation and proactive intelligence will be further improved, personalisation of multimodal feedback will be optimised, more comprehensive user tests and clinical validations will be carried out, and the products will be made smarter, thinner, lighter, emotionally responsive and more accessible to provide a safer, friendlier and warmer smart wearable experience for more people.

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