Advances in Engineering Research : Possibilities and Challenges
ISSN Print: 3079-5192
ISSN Online: 3079-5206
https://doi.org/10.63313/AERpc.9001

Engaging Interaction and Intelligent Experience: Innovative Design Research of Phototherapy Beauty Devices from a Multimodal Perspective

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How to cite this paper:
Huang, M., Zhang, M., & Zhang, Y. (2025). Engaging Interaction and Intelligent Experience: Innovative Design Research of Phototherapy Beauty Devices from a Multimodal Perspective. Advances in Engineering Research: Possibilities and Challenges, 1(1), 1-16. ISSN Print: 3079-5192; ISSN Online: 3079-5206.
Published:2025-03-07
https://doi.org/10.63313/aerpc.9001

Abstract

The home-use phototherapy beauty device has a high market penetration rate, but its single interaction mode and lack of personalization limit the further enhancement of user experience. To address these issues, this research, based on multimodal interaction design theory, proposes an innovative design solution for phototherapy beauty devices as smart wearable products. Firstly, user requirement elements were analyzed and ranked for their weight using Python web scraping technology, the KJ method (Affinity Diagram), and the AHP (Analytic Hierarchy Process), thereby determining the key design requirements for the phototherapy beauty device. Secondly, the multimodal interaction information architecture of the device was reconstructed, and the key user needs were translated into corresponding functional design directions for design reasoning, resulting in a new product functional framework. On this basis, specific design proposals, such as integrating a directional audio player, optimizing the interaction interface, adding a detachable eye protection lens, and adopting a rotating folding structure, were suggested. These aim to enhance the product's fun, usability, and safety, thereby optimizing the user experience and providing theoretical and practical guidance for the innovative design of phototherapy beauty devices and similar smart wearable products.

Keywords

Phototherapy Beauty Device; Multimodal Interaction; Web Scraping; KJ Method (Affinity Diagram); Analytic Hierarchy Process (AHP)

1. Introduction

With the growth of economic income and changes in consumer attitudes, people’s pursuit of beauty has significantly increased, driving the rapid expansion of the “self-pleasure” consumer goods market, particularly in the personal care and beauty small appliance market, including beauty devices and facial cleansing devices. (Meng, Y., & Chen, H. ,2021), Over the past decade, the scale of this industry in China

has continuously expanded, with sales exceeding 50 billion yuan, a fourfold increase compared to 2014. (Wu, Y., 2024), However, the industry is now facing challenges posed by upcoming regulations. Starting in April 2024, home-use beauty devices will be categorized as medical devices, requiring products such as radiofrequency devices to obtain medical device registration certificates before they can be manufactured, imported, or sold. (Hou, T., 2024), This change signals the beginning of a rapid transformation for the beauty device industry, with product safety and effectiveness becoming central considerations.Currently, the home-use phototherapy beauty device market is characterized by numerous brands and diverse functions, yet it faces issues such as potential eye health risks from light exposure and poor facial fit. Addressing these issues through improvements and innovative designs based on user needs is of paramount importance. This study integrates user demand analysis through online reviews with the Analytic Hierarchy Process (AHP) and draws on multimodal interaction theory to construct a research framework. Multimodal research has garnered significant attention in fields such as computer science and linguistics, and its methods and theories offer valuable insights for the design of smart wearable products. By conducting this research, we aim to translate latent user needs into specific design elements and propose design strategies for home-use phototherapy beauty devices. These strategies aim to achieve engaging interaction and intelligent user experiences, providing theoretical and practical guidance for the development of smart wearable products.

2. Research Framework

This study is guided by multimodal interaction theory and utilizes Python web scraping technology to mine user online review data. The KJ method is employed for brainstorming, and the Analytic Hierarchy Process (AHP) is used to comprehensively rank the weight of demand elements. The top-ranked demand elements are selected as the focus of design. The process is divided into the following four stages.

First, user requirements are obtained based on online reviews. In the context of the internet, online review data has become an emerging source of user demand information, containing a large amount of authentic and accurate emotional user demands (Tian, P., & Yang, Q., 2024,). RAY and others (Ray, P., & Chakrabarti, A., 2017, February) collected online reviews from shopping websites using Python web scraping technology. Through data cleaning, keyword extraction, and statistical analysis, they built a customer consumption preference model. Kim and others (Kim, S. G., & Kang, J., 2018)combined sentiment analysis of review data with the LDA model to conduct a comparative analysis of two competing beauty products. As a highly active and best-selling product on shopping platforms, phototherapy beauty devices are suitable for using web scraping technology to collect and analyze user demands. This study retrieves user online reviews from the JD platform, collects user requirements, and constructs a high-frequency attribute evaluation word set.

Second, the affinity diagram (KJ method) is used to integrate and categorize the re-

sults of the online review analysis. The team members organized the results obtained from the web scraping phase, along with the ideas of the group members and the collected data. This approach helps to some extent compensate for the limitations of a single method. However, the results still carry a certain degree of subjectivity, and there are shortcomings in terms of comprehensiveness of evaluation and handling of optimization issues. To address these limitations, the Analytic Hierarchy Process (AHP) is introduced to fill this gap.

Third, user demand weights are calculated based on the Analytic Hierarchy Process (AHP). The AHP method can scientifically calculate the weight values of various indicators, providing significant scientific rigor and logical consistency, which helps designers perform hierarchical evaluations and make comparative rankings (Madzík, P., & Falát, L, 2022). In product design, Liang Hao ang others (Liang, H., Liao, X., Huang, S., 2023) proposed a "triangle strap" compressed oxygen self-rescue device design based on AHP, with a focus on the wearing method. Wei Wei and others (Wei, W., Zhang, L., Wang, S.,Wei, W., Zhang, L., Wang, S., et al., 2023) applied the AHP method to the conceptual design of snow rescue equipment, clarifying its functionality, appearance, ergonomics, and technical requirements. Additionally, Zhong Guangming and others (Zhong, G., Zhang, Y., Fu, X., 2023) innovatively applied the AHP method to guide the development of adjustable children's seating products, enhancing the scientific and rational basis of the design and increasing consumer satisfaction.

Finally, based on the multimodal interaction theory, design thinking is transformed, and a corresponding multimodal interaction information architecture is constructed, leading to the development of the product function framework for the phototherapy beauty device. Upon completion, the design enters the practical phase, focusing on five key aspects: comfort and fit, convenient storage, eye protection, emotional soothing, and ease of operation. The result is a new product design proposal for the phototherapy beauty device.

In summary, by integrating Python web scraping, the KJ method, the Analytic Hierarchy Process (AHP), and multimodal interaction theory, a user-demand-driven product design model is constructed. This model offers advantages such as precise user demand identification, efficient design decision-making, and a complete design process, ensuring that the design proposal goes beyond the intuitive level.

3. Feasibility Analysis of Introducing Multimodal Interaction Theory into Phototherapy Beauty Instruments

3.1. Multimodal Interaction Theory

Multimodality refers to a collection of diverse forms of expression, utilizing various carriers and approaches to engage multiple senses (such as hearing, vision, touch, smell, taste, etc.), with the goal of interacting with the surrounding environment (Zhang, L., 2017). In terms of information interaction, modalities play the

role of communication channels and carriers. Many scholars, both domestically and internationally, have conducted in-depth research on multimodal interaction theory. Norris (Norris, S., 2009) proposed that to determine the modal configuration in information interaction, three core questions must be answered: which modalities are essential; which modality has higher priority when compared between modalities; and which modalities, although not essential, are still used by the activity participants. Bangli Shao and others (Shaoh, B., Zhu, Y., Zhu, R., et al., 2021) applied multimodal information interaction theory in the field of smart homes, effectively enhancing the fluency of human-computer interaction. Nuovo and others (Nuovo, A., Broz, F., Wang, N., et al., 2018) proposed a multimodal input interface for elderly groups, with experimental results showing that the interface significantly improved cognitive assistance and compensation for the elderly.

In addition, multimodal interaction theory can be applied in the design of wearable products to achieve efficient and natural human-computer dialogue. By utilizing multiple sensory channels, it is possible to align natural behaviors with wearable product design. Based on ergonomic principles, Many scholars explored the coordination between wearable products and users, thereby significantly enhancing product usability, practicality, and safety. Xi Zeng and others (Zeng, X., Cui, X., 2023) used the Hierarchical Task Analysis method to explore how different combinations of modalities impact product usability, and based on this, they designed a modal-flexible, smart wearable augmented reality helmet, significantly enhancing interaction efficiency.

3.2. Feasibility Analysis

Currently, phototherapy beauty devices primarily adopt a touch-based unimodal interaction, which limits the capacity and makes the process rigid, failing to fully meet user needs. Therefore, enriching the human-computer interaction modes is one of the key areas of current research. Additionally, as an intelligent wearable product, the phototherapy beauty device has the ability to simulate the human sensory system. It can collect signals through sensory systems such as vision, hearing, and touch, and use technologies such as image recognition, voice recognition, semantic understanding, and data analysis to acquire information (Nizam, S. M., Abidin, R. Z., Hashim, N. C., et al. 2018). The multimodal information interaction process of the phototherapy beauty device, oriented towards both users and products, is divided into three stages .

First, multimodal information acquisition. The intelligent sensory system of the phototherapy beauty device collects modal information such as images, sounds, touch, and environmental data from the real-world scenario. With user permission, this information undergoes intelligent analysis, including image recognition, voice recognition, semantic understanding, command recognition, and data analysis (Norris, S., 2004).

Second, multimodal information fusion and processing. Currently, the continuous

evolution of machine learning, especially deep learning, has led to significant advancements in both computer vision and natural language processing (Talaei Khoei, T., Ould Slimane, H., & Kaabouch, N., 2023). The intelligent analysis system can achieve the fusion and processing of multimodal information, and it processes the modal relationships and temporal relationships to enable achievable interactive logic.

Third, multimodal information feedback. The intelligent control system processes the data obtained from multimodal information analysis to provide real-time feedback on visual, auditory, tactile, and other sensory information based on user intent and changes in the scenario. This enables the system to generate relevant information feedback that meets user needs, which is ultimately mapped onto the product design through output devices.

In summary, based on the product characteristics of the phototherapy beauty device and utilizing multimodal interaction theory, the integration of multimodal interaction formed by the advantages of multiple senses can effectively reduce the user's operational burden, improve human-computer interaction efficiency, and enhance product usability and safety. Furthermore, this interaction method can provide insights for the development of similar smart wearable products and offer new approaches for optimizing user experience.

4. User Demand Acquisition Based on Online Reviews

4.1. Comment Data Mining

Utilizing internet technology to analyze online user reviews can enhance the efficiency of user demand collection, which is crucial for user demand research in the field of design. These online review data are obtained through web scraping tools, also known as Web information collectors. As a core component for acquiring information through search engines, web crawlers automatically capture web content and data according to preset rules. They are widely used in large-scale web data search and collection and are a key tool in current big data research. Consumer reviews on online shopping platforms directly reflect users' experiences with products, mapping actual user needs and effectively reducing the interference of subjective influences (Li, R., Wu, Y., & Zhi, J., 2020). In this study, the sample was selected from the well-known domestic e-commerce platform—JD.com, which, with its highly active consumer base, provides precise consumer review information and accurate user profile descriptions. After considering factors such as clarity, online sales, appearance similarity, and camera angle similarity, 10 popular models of phototherapy beauty devices, each with different styles and brands, were selected. Using the Python web scraping tool, 200 positive, neutral, and negative reviews were extracted for each of the 12 phototherapy beauty devices, totaling 7,200 user reviews as the initial data.

4.2. Comment Data Preprocessing

The obtained initial data needs to undergo appropriate preprocessing to meet the standards for knowledge mining using the Apriori algorithm. The Apriori algorithm, based on association rules, primarily functions to identify associated itemsets in large-scale datasets, thereby generating association rules (Li, J., & Zhang, W., 2021). In the Apriori algorithm, the support of an event (or attribute) Y, denoted as SUPP(Y), can be calculated using the following formula:

$$SUPP\ （Y）= \frac{M\ （Y）}{M}$$
$$M\ （Y）= \sum_{i=1}^{M} Ii\ （Y）\tag{1}$$

In this formula, Y represents a specific event (or attribute), M is the total size of the dataset, and SUPP(Y) denotes the support level of Y. Additionally, Ii(X) is the indicator function for the i-th item that appears with Y. If the support of Y, SUPP(Y), meets a predefined threshold, the itemset {Y} is defined as a frequent itemset, reflecting the high-frequency attention users give to the product attributes.

The steps for obtaining user online reviews using the Python web scraping script are as follows: (1) Requirement acquisition, (2) Requirement processing and analysis, (3) Requirement transformation. The overall model for online review data mining is shown in Figure 1.

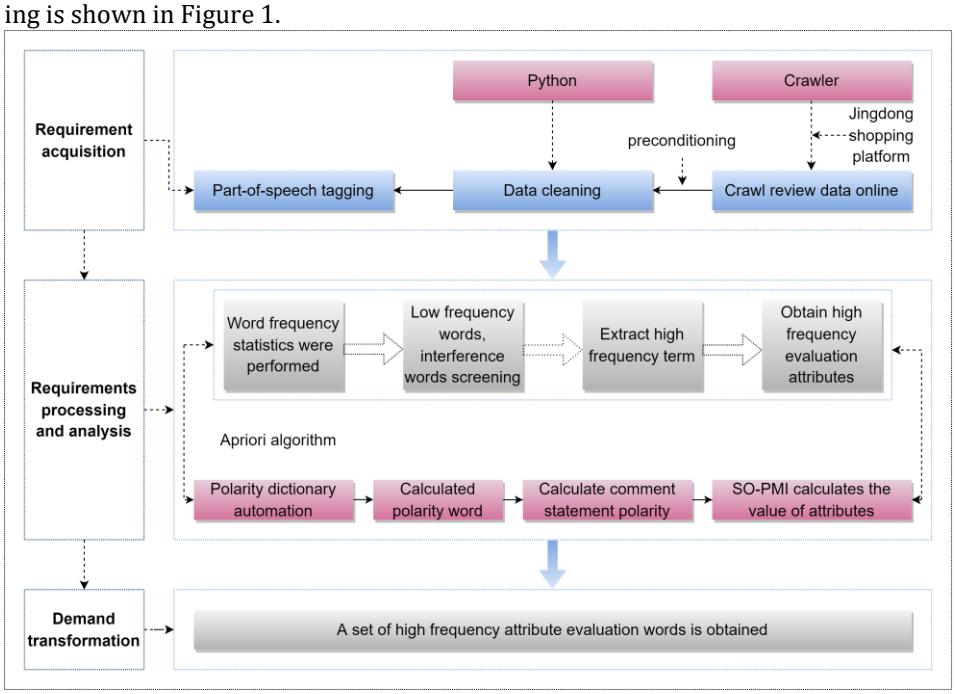

Figure 1. Overall Model of Online Review Data Mining.

Firstly, in the requirement acquisition phase, the Python program is used to obtain

the source code of the review web pages. The ICTCLAS3.0 Chinese word segmentation tool is employed to perform word segmentation and part-of-speech tagging on the online review data.

Secondly, in the requirement processing and analysis phase, the words after segmentation are first filtered, organized, and summarized, and an attribute dictionary is then established. Based on the established attribute dictionary, the review data undergoes further filtering and cleaning, resulting in 2,216 valid review entries. Subsequently, the Apriori algorithm, based on association rules, is used to focus on identifying correlated itemsets from the large dataset. The Apriori algorithm is applied to the valid review data to mine frequent itemsets, with a support threshold set as SUPP(Y) = 0.1. Meanwhile, the SO-PMI algorithm is employed to calculate the evaluation values of the product attributes. This study provides a comprehensive analysis of the impact of adverbs, negation words, and polarity words on sentence meaning construction, and uses specialized formulas to determine the sentiment intensity of the sentences, thereby deriving a comprehensive evaluation of the product attributes.

Finally, in the requirement transformation phase, based on the above analysis, the set of high-frequency attribute evaluation values is obtained and stored in a categorized manner.

4.3. Comment Results Analysis

From the perspective of product design, the user demands collected through web scraping are categorized according to their objective relationships, followed by hierarchical attribute classification. This analysis divides the attributes of the phototherapy beauty device as an intelligent wearable product into five main levels: functional requirements, interactive experience, safety and comfort, intelligent control, and voice broadcasting. Based on this framework, the team has statistically analyzed the frequency of user reviews for the phototherapy beauty device and their proportion within each attribute level. The relevant data is detailed in Table 1.

Table 1. User review frequency and the proportion of each attribute level.

	Attribute words	User review examples	Frequency/Times
Basic functions	Functional Area	Area, Zone, Interval	298
	Storage	Fold, Unfold, Place, Set aside	306
	Number of Lights	Number of lights, How many lights, How many units	155
	Personalization	Personality, Preference, Liking	254
Interactive experience	Operation	Using, In use, Use	207
	Interface	Interaction, Display screen, Screen	199
	Voice	Speech, Sound, Music	188
	Dialect	Dialect, Local language, Accent	235
	Tactile sensation	Interaction, Communication, Mutual	301
	Group	Crowd, Masses, Group of	257

	Attribute words	User review examples	Frequency/Times
		people	
Safety and comfort	Material	Material, Sourcing material, Selecting material, Using material	297
	Light source	Red and blue light, LED, Yellow light, Red light	311
	Eye protection	Eye area, Around the eyes, Eye fatigue	289
	Conform	Fit to face, Stick, Adhere, Suitable, Facial contour	269
Intelligent control	Recognition	Distinguish, Identify, Discover	122
	Remote	Operation, Control, Manipulate	191
	Learning	Learn, Acquire, Understand	259
Intelligent voice reporting	Timeout	Time, Too long, Abnormal, Forgot to turn off	327
	Broadcast	Play, Convey, Teach	216
	Soothing	Relieve, Decompress, Unwind	287

5. User Demand Weight Analysis Based on AHP

5.1. Construction of Hierarchical Analysis Model

The first step in constructing the Analytic Hierarchy Model is to assemble a team of senior experts in the field to comprehensively collect information on user demands from various aspects. Then, these demands are subdivided, summarized, and integrated into a classification system with different hierarchical levels (Bolat, P., Kayişoğlu, G., Gunes, E., et al.,2020). To this end, an expert team was formed by inviting 2 product designers, 2 design professors, 1 student majoring in product design, 2 professionals in the phototherapy beauty device industry, and 2 loyal consumers of phototherapy beauty devices. Using the Affinity Diagram (KJ) method, the team listed the consumer demands for the phototherapy beauty device and categorized similar demand expressions (Hou, J., Hu, H., & Xie, Z., 2022). The research group searched for a large number of articles, reviews, and other relevant materials related to users and phototherapy beauty devices through platforms such as JD.com, Zhihu, Xiaohongshu, and CNKI. These secondary materials, along with the ideas from the team members and user review-related statements obtained via web scraping, were all compiled. Based on similarity, they were merged into approximately 10 categories, with each major category being named. The logical relationships between different categories were analyzed and connected using different arrow symbols.

Using the Affinity Diagram (KJ) method, combined with the attribute-level indicators derived from Table 1, the demands were categorized into five major levels: basic functions, interactive experience, safety and comfort, intelligent control, and smart broadcasting. Ultimately, the top five criterion levels and 20 solution levels most

important to users were identified. Based on this, the Analytic Hierarchy Model for the phototherapy beauty device as an intelligent wearable product was established (as shown in Figure 2).

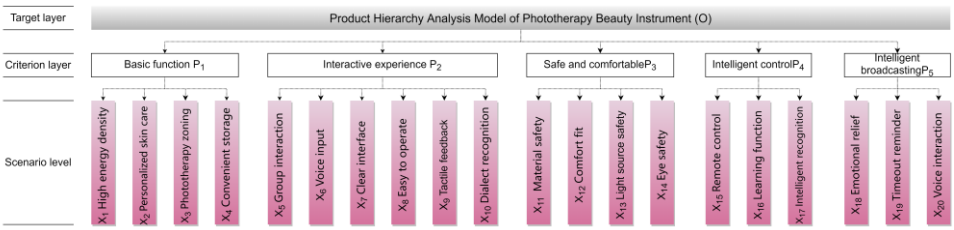

Figure 2. Hierarchical Analysis Model of Smart Wearable Light Therapy Beauty Device.

5.2. Construction of Judgment Matrix and Weight Calculation

After categorizing the user demands for the phototherapy beauty device, the next step is to determine the scale and construct the judgment matrix. First, the 1-9 scale theory (Hu, K., Qiu, J., & Ai, X., 2019) is used as the basis for the judgment matrix scale. Then, the judgment matrix is constructed and normalized to derive the weight vector for the goal layer and each criterion layer. The judgment matrix and weights for the goal layer P are shown in Table 2.

Table 2. Goal layer P judgment matrix and weights.

P	P1	P2	P3	P4	P5	w
P1	1	1	1	3	1/2	0.2110
P2	1	1	1	2	1	0.2235
P3	1	1	1	1	2	0.2235
P4	1/3	1/2	1	1	1/2	0.1184
P5	2	1	1/2	2	1	0.2235

To ensure the scientific and rationality of the matrix judgment scores, consistency verification must be conducted. If the consistency ratio (CR)$\leqslant$0.1, it indicates that the data inconsistency is within the allowable limit, and thus the consistency check is passed. Conversely, if CR$>$0.1, the matrix does not pass. The calculation method for the CR value is as follows:

$$CR = \frac{\lambda_{\max} - n}{(n-1)RI} \tag{2}$$

In the formula, the maximum eigenvalue of the matrix is denoted as λ max, the order of the judgment matrix is represented by n, and RI is the average consistency index. Based on this, consistency checks were performed for the goal layer O and criterion layers P1 – P5. The results showed that the CR values for all layers were

less than 0.1 (as shown in Table 3). After passing the consistency check, the weight values of the solution layers were multiplied by the corresponding criterion layer weights to obtain the comprehensive user weight values for the phototherapy beauty device (as shown in Table 4).

Table 3. Consistency test results.

	P	P1	P2	P3	P4	P5
max	5.3252	4.0457	6.4614	4.0457	3.0536	3.0183
RI	1.1200	0.9000	1.2400	0.9000	0.5800	0.5800
CI	0.0813	0.0152	0.0923	0.0152	0.0268	0.0091
CR	0.0726	0.0169	0.0744	0.0169	0.0462	0.0158

Table 4. Comprehensive Judgment Matrix Weight Values of Design Elements.

Primary Indicator	Weight	Secondary Indicator	Weight	Comprehensive Weight	Weight Ranking
P1	0.2110	X1 High energy density	0.2452	0.0517	9
		X2 Personalized skin care	0.0905	0.0191	17
		X3 Phototherapy zoning	0.2916	0.0615	6
		X4 Convenient storage	0.3727	0.0786	4
P2	0.2235	X5 Group interaction	0.0684	0.0153	19
		X6 Voice input	0.1738	0.0388	13
		X7 Clear interface	0.2273	0.0508	10
		X8 Easy to operate	0.3816	0.0863	2
		X9 Tactile feedback	0.1006	0.0225	16
		X10 Dialect recognition	0.0438	0.0098	20
P3	0.2235	X11 Material safety	0.0890	0.0181	18
		X12 Comfort fit	0.3413	0.0763	5
		X13 Light source safety	0.2029	0.0453	12
		X14 Eye safety	0.3667	0.0820	3
P4	0.1184	X15 Remote control	0.4934	0.0584	7
		X16 Learning function	0.1958	0.0232	15
		X17 Intelligent recognition	0.3108	0.0368	14
P5	0.2235	X18 Emotional relief	0.5499	0.1229	1
		X19 Timeout reminder	0.2402	0.0537	8
		X20 Voice interaction	0.2098	0.0469	11

6. Product Design Strategy Based on Multimodal Interaction

Against the backdrop of the deep development of artificial intelligence technologies and mobile communication networks such as 5G, the multimodal information interaction of intelligent wearable products will become more user-friendly, providing higher-quality services to phototherapy beauty device users. To ensure the efficiency of multimodal interaction in intelligent wearable products, the primary task is to appropriately select the modalities used for information presentation . Typically,

modalities with higher flexibility and recognition accuracy, such as audiovisual modalities, are preferred as the dominant modality, while other modalities, such as haptic, are considered secondary. Users determine the object based on the dominant modality and use the secondary modality to select and execute tasks. Once completed, the system provides corresponding feedback (as shown in Figure 3).

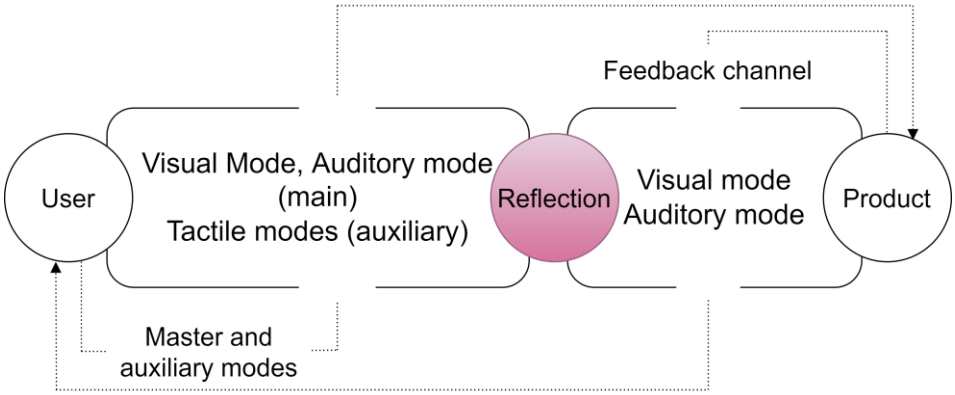

Figure 3. Modal Selection.

Based on the above analysis, the interactive information architecture is constructed according to the modalities involved. The architecture is divided into four modules: basic information of the phototherapy beauty device, wearable experience, appearance perception, and operation process. Among these, the wearable experience is primarily presented through haptic feedback, enabling users to intuitively sense it in the usage context. Appearance perception information is mainly conveyed through visual and tactile modalities. During the operation process, a combination of visual and auditory modalities is primarily used, with touch as supplementary support, aiming to improve the accuracy of interaction .

Starting from user demands and based on the weight ranking results derived from the AHP analysis, the top five demand elements in Table 9 were extracted , which are X19 Emotional Relief, X5 Ease of Operation, X12 Eye Safety, X2 Easy Storage, and X11 Comfortable Fit. These were grouped into a prioritized design element set. Combining this with the multimodal interaction information architecture in Figure 7, the user demands were transformed. The design focuses on several aspects, including the convenience of the phototherapy beauty device, eye safety, stable structure, facial fit, ease of storage, and emotional relief. Finally, a design concept applying multimodal interaction theory to the phototherapy beauty device was developed, resulting in the functional framework for the intelligent wearable phototherapy beauty device (as shown in Figure 4).

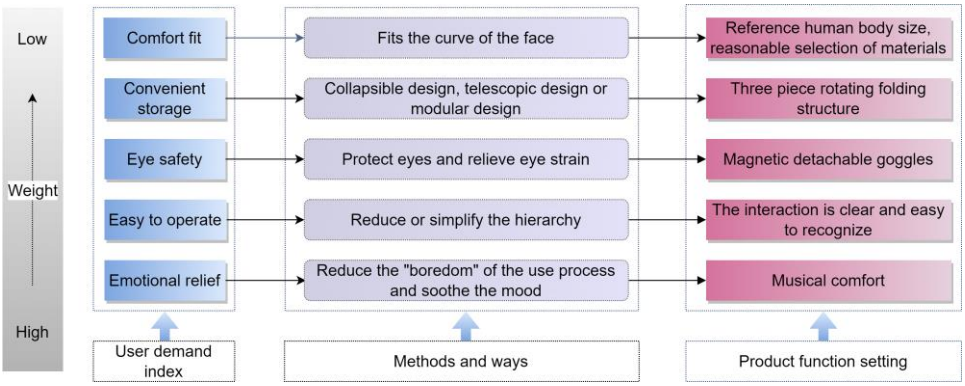

Figure 4. Phototherapy Beauty Device Product Function Framework.

6.1. Music Soothing

During the use of the phototherapy beauty device, users may avoid frequent eye usage, which can lead to difficulty passing time, making the process feel monotonous. Since auditory senses are one of the most efficient means of information delivery, the phototherapy beauty device can integrate a directional audio player. This player uses a specialized audio processor and algorithm, which can precisely direct open sound to a designated area near the ears. Additionally, it can connect with the user's mobile app to play music through the audio player, reducing feelings of "boredom," "monotony," and "drowsiness" during the wearing process. This enhances the interactive experience by adding an element of fun and can also improve the user's perception of time while providing emotional comfort.

6.2. Clear and Easily Recognizable Interaction

Reducing or simplifying the hierarchical structure is an important factor in improving system usability, as it helps avoid triggering psychological anxiety in users when faced with a complex and functionally cumbersome interface. The design of intelligent wearable phototherapy beauty devices should focus on the proficient use of graphical elements, enhanced color recognition, optimized text presentation, simple and intuitive layout arrangements, and simplified touch control operations to ensure that the interactive interface is clear and easily recognizable. This improves the communicability of information and enables users to quickly access the content they need. For example, in terms of touch control operations, the interaction design of the phototherapy beauty device should simplify the touch controls while ensuring diverse feedback for touch actions. The right side of the device is equipped with a touch button, and the position and angle of the button are designed to be within easy reach of the user's arm during wear, ensuring convenient operation. These touch buttons support basic actions such as tapping and rotating, allowing users to select the desired settings and beauty programs with one hand. After the operation is complete, users receive voice feedback to provide immediate auditory responses.

6.3. Detachable Goggles

In the design of the eye area, considering that prolonged use and frequent eye exposure in phototherapy beauty devices can lead to fatigue and even dizziness, affecting eye health, a detachable magnetic eye shield is added to the basic LED phototherapy beauty device. First, it effectively blocks LED light, preventing direct eye exposure and improving eye comfort during wear. Second, during use, the eyes are in a relaxed state, and an eye protection design can be achieved using mist circulation technology. Mist circulation technology is an advanced water treatment method primarily used to improve water penetration efficiency and reduce water consumption. The basic principle of this technology is to use mist instead of traditional liquid water for penetration, increasing the surface area of the water to improve its penetration efficiency. During the steam massage, it can simultaneously perform eye acupoint vibration massage and hot compress, effectively reducing the risk of eye damage and enhancing the tactile interaction experience. Additionally, the detachable eye shield allows users to subtly divert their attention while receiving facial light therapy, reflecting the mutual feedback of the tactile and auditory modalities. This can enhance the interactive experience's entertainment value and reduce feelings of boredom.

6.4. Rotatable Folding Structure

If the phototherapy beauty device uses a traditional integrated face mask, it would not accommodate the unique facial contours of every user, and due to its large surface area and volume, it would be inconvenient to carry and store. Therefore, the new phototherapy beauty device can adopt a three-piece foldable structure resembling a fan, similar to the transparent structure on motorcycle helmets. The folding structure allows the left and right sides to serve as pivot points, enabling them to rotate within a certain range relative to the axis, which provides better adaptability to different users' facial curves during wear. When the product is not in use, it can be folded into a one-piece compact form, saving storage space.

6.5. Reference to Human Body Dimensions and Rational Material Selection

The structure design of the phototherapy beauty device is based on the dimensions of the human head and face. While considering the minute details, a light energy chamber is formed, with the light source wrapping the entire face in a 360° manner, making the energy more concentrated. By fitting the facial angles, it enables direct and precise irradiation, improving the absorption of light energy by the face and enhancing usage efficiency. In the specific design, the differences in users' head and face dimensions should be fully considered, ensuring that the device accommodates the various head and face sizes of different female users to ensure comfort and stability during wear. The product dimensions are determined with reference to some basic data provided in reference (Zhang, Z., & Cheng, X., 2017).

To reduce pressure on the head and face during wear, lightweight materials with impact-resistant properties are selected. The main shell of the phototherapy beauty device can be made from engineering plastics, which have characteristics such as shock resistance, anti-collision, and anti-deformation, making it both lightweight and durable. The inside of the face mask uses lightweight silicone, which is soft and skin-friendly. Additionally, the product incorporates a suspension device and extends the nose support surface to effectively increase the contact area with the skin, allowing for a more even distribution of pressure. These designs aim to enhance the comfort of users during wear.

6. Conclusion

With the development of multimodal sensing and interaction technologies, intelligent wearable products based on multimodal information interaction offer more possibilities for the design of phototherapy beauty devices. Guided by user needs obtained from online reviews, the AHP hierarchical analysis method is introduced to determine the user demand weights. The multimodal interaction theory is then comprehensively applied to the innovative design of the phototherapy beauty device, creating a multimodal interaction information architecture. This study explores the diversified needs of users in different usage scenarios and proposes a multimodal-based interaction design strategy for phototherapy beauty devices. The design offers advantages such as convenience, efficiency, eye protection, facial size fitting, easy storage, and an engaging interactive experience. By deeply integrating the unique advantages of various senses, the efficient and collaborative multimodal interaction information complementary mechanism significantly reduces the cognitive load on female users in the usage environment, thereby enhancing the efficiency and safety of human-computer interaction. To address the homogeneity issue of phototherapy beauty devices, the method proposed in this study effectively captures the core needs of users, providing design professionals with innovative entry points, guiding new design directions, and enhancing the user experience. However, subjective judgment from designers may become an interfering factor when identifying core user needs. Therefore, it is recommended that future research introduce more rigorous and objective quantitative analysis methods to more precisely filter and clarify the core user needs.

Acknowledgements

This research was financially supported by the Zhejiang Provincial Department of Education Visiting Engineer "University-Enterprise Cooperation Project" (Project No. FG2024081) and the Teaching Construction and Reform Research Project of Wenzhou Polytechnic (Project No. WZYzd202402).

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