Usability and User Experience, Vol. 110, 2023, 443–453
https://doi.org/10.54941/ahfe1003219

Construction of Key Index System of Product Usability Design Based on User Operation Behavior -- An Example of the Intelligent Ultra-Cryogenic Refrigerator

Ping Zhang[1], Hanyu Wang[1], Haokun Tian[2], and Ruzhong Li[1]

[1]Hefei University of Technology, Hefei 230601, China
[2]University of Birmingham, Edgbaston Birmingham B15 2TT, United Kingdom

ABSTRACT

Nowadays, the increasing complexity of product functions and the convenience of operation is producing a contradiction, which leads to the widespread availability of products. In view of the mismatch between product usage and user behavior logic, this study systematically analyzed the usage of product from the perspective of user behavior logic by exploring the usability requirements of intelligent ultra-cryogenic refrigerators, since they can speed up medical research and promote industrial development. This paper used the theory of usability engineering to combine usability requirements with product design elements. Correlation co-efficient and weight were calculated by gray correlation analysis and the order relation analysis, so the key indicators of usability design of product would be extracted, which could provide references for product optimization design, quantify user demand, improve product usability, and realize the interaction- mixing-symbiosis mode between human and intelligent machine. By effectively matching user knowledge with design knowledge, this study constructed the key index system of product usability design, enriched the theoretical system of human-computer interaction design and usability, and provided decision-making basis for iterative innovative product design and rational allocation of resources.

Keywords: Behavior logic, Product usability design, Key indicators, Intelligent ultra-cryogenic refrigerator

INTRODUCTION

The intemperance and imbalance of design and consumption have brought series of negative effects to human society. The commercialized design that caters to people's material desire not only meets the diversified needs of users, but also intensifies the contradiction between the complexity of product functions and the ease of operation. This results in the ubiquitous usability problems of products, so user-centred design is needed to fully consider human-machine coupling. It is one of the core issues that needs to be considered in the process of product development and design to improve the usability of products by effectively matching user knowledge with design knowledge.

Under the tide of experience economy, domestic and foreign scholars' research on product usability gradually increases, mainly focusing on usability design and evaluation methods. Zhou, RG proposed a general usability evaluation method aiming at the fuzziness and uncertainty of users in product design attribute judgment, by combining the analytic hierarchy process (AHP) with fuzzy evaluation method (Ronggang Zhou & Alan H. S. Chan 2016). Su Jianning's team firstly took automobile keys as an example to study product modelling design characteristics and attributes. Then they constructed an evaluation index model from the aspects of perceived usability and performance usability. Finally, they proposed a product modelling design usability evaluation method based on naive Bayes method (Su Jianning et al. 2016). Li Yongfeng subdivided product usability into appearance, perception, and performance, and applied AHP method to construct product usability evaluation system (Li Yongfeng & Zhu Liping 2012). Liu Long solved the problem that existing methods only evaluate the overall usability of products. He proposed a quantitative usability assessment method based on failure mode and effect analysis (FMEA), and calculated the usability level of products through the analysis and evaluation of product task set (Liu Long & Liu Huchen 2010). Zeng Dong obtained the usability related knowledge through the extraction of design knowledge and user knowledge, and analysed the usability problem of product hardware interface (Zeng Dong & Chen Yaming 2008). It could be seen that existing literature largely relied on the judgment of product design attributes, and the evaluation model was mainly constructed based on the mutual affinity of the indicators, so these methods rarely consider the internal uncertainty and fuzziness in the process of judgment. This study constructs the key index system of product availability design through demand visualization, by combination of grey association analysis method and sequence relations, goals like quantitative analysis of the demand from the vertical dimension layer and design elements, improvement of the evaluation system, effectively transformation of user intention into design schemes can be achieve. Also, it can help enterprises to effectively optimize resource allocation, reduce production costs, improve product market competitiveness and increase user satisfaction.

BEHAVIORAL LOGIC'S NORMAL FORM OF INTELLIGENT ULTRA-CRYOGENIC REFRIGERATOR

Human-computer interaction visualization includes data visualization and requirement visualization. Designers choose appropriate information representation form based on user needs, so that users could receive information and give orders naturally and smoothly, that is, demand visualization (Zhang Lin & Zhao Jing 2015). The requirements of users can be obtained by analyzing their operation behavioral logic. Both physical logic and behavioral logic belong to decision logic in product design process(Xin Xiangyang 2015). "Physical logic" emphasizes the rational disposition of the attributes of the object itself, while "behavioral logic" pays more attention to the design of user behavior by following human behavior, purpose, and habit to plan the behavior process, construct the common position between human and machine, and create the interaction-mixing-symbiosis mode between human and intelligent machine (Alan Cooper et al. 2012).

Based on the hierarchical progressive behavioral logic model of behavioral cognition, interaction and experience, the usage mode of intelligent ultra-cryogenic refrigerator was systematically analyzed (see Figure 1). The mapping relationship between behavioral semantics conveyed by design elements such as product shapes, structures, and functions were clarified, while the behavioral path was rationally planned to realize the natural interaction between human and computer.

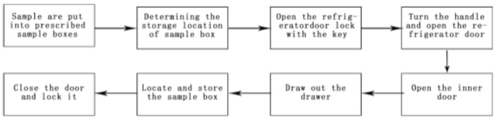

Figure 1: The logical model of behavior.

Behavioral cognition is the information processing of product usage from the perceptual point of view, which provides decision-making basis for human-computer interaction. According to the use process of intelligent ultra-cryogenic refrigerator, the behavioral cognitive semantics are obtained and described dynamically (see Figure 2). In order to provide users with real-time and effective behavior order, action, state, and feedback instructions, the intelligent ultra-cryogenic refrigerator should be decomposed into simple and direct symbolic elements, projecting its shape, material, time, space, and other multi-dimensional semantic information.

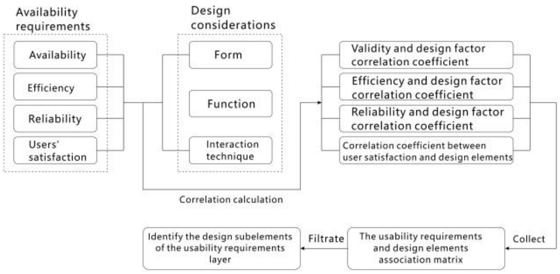

Figure 2: The usage behavioral logic of intelligent ultra-cryogenic refrigerator.

Behavior interaction is to represent and extract behavior phenomena in the process of product operation, as well as deconstruct behavior actions and sequences according to space and time dimensions. Based on the contribution degree as a specific measurement criterion, the primary and secondary subordinate relationships of behavior are distinguished, and the direct action based on the core function of "cryogenic storage sample" product is extracted to represent the sequence of behavior: open door → search (sample storage location) → storage → closure (see Figure 3). The key to the successful interaction between users and machines is how to find the sample storage location quickly and accurately, avoid the biochemical reaction of samples caused by frequent door opening and temperature rising, which could help to provide a long-term stable storage environment, and enhance the availability of products.

Figure 3: The usage behavior path of users.

Behavioral experience is a comprehensive emotional experience formed by integrating cognition and operation. Intelligent ultra-cryogenic refrigerators are different from ordinary household refrigerators. Because of the special function of ultra-low temperature storage samples, users have higher requirements for their usability and pay more attention to safety, comfort, and reliability of product usage.

Usability requirements of intelligent ultra-cryogenic refrigerator include appearance availability, operational availability, and perceived availability. Appearance usability means that products interact with users through visual means such as shape or color, and the usability they present. Reasonable layout of design language can effectively convey behavioral semantic information for users. Operational usability refers to the feelings brought by the efficiency, performance, and feedback of the product in the specific use process, which would follow the users' behavior path and optimize the configuration of functional elements to help users completing tasks quickly and efficiently. Perceived usability refers to the integration of visual, auditory, tactile, etc. multi-sensory interaction, the subjective impression and real feeling of usability that users may perceive during the task execution stage, which would lead to a comfortable and pleasant interactive experience.

RELEVANCE ANALYSIS OF AVAILABILITY REQUIREMENTS AND DESIGN ELEMENTS

Availability Requirements of Intelligent Ultra-Cryogenic Refrigerator

Usability is a quality indicator to measure interactive systems or industrial products (NIELEN J.k. 2004). Originally derive from ergonomics, it focuses on the reliability and maintainability of industrial products. In recent years it has gradually extended to the field of interactive system design. According to the ISO 924–11 standard, usability is the degree to which a product could be effectively, efficiently, and satisfactorily achieved by a particular user in a particular context. The usability attributes of industrial products and computer interaction interfaces are different due to their own characteristics.

The intelligent ultra-cryogenic refrigerator had the dual characteristics of industrial product and computer display interface. As an effective manager of biological sample or special work piece, it is mainly used in medical treatment and scientific research. The users are highly dependent on the reliability of the product and strictly control the temperature accurately and stably to avoid the influence of temperature fluctuations on sample quality. The display control system is not as complex as the computer interaction interface and has low demand for learnability and memorability.

Based on the comprehensive availability requirements and the functional characteristics of the product, the availability requirements of the intelligent ultra-cryogenic refrigerator are finally determined as effectiveness, efficiency, user subjective satisfaction and reliability.

Computation of Weight of Availability Requirements

Comprehensive analysis was used to determine availability requirements indicators: firstly effectiveness (UR1), efficiency (UR2), reliable (UR3) and user satisfaction (UR4) were labelled, then five usability experts and three rival firms were invited to score the indicators from 9 (very important) to 1 (very unimportant) respectively, after that the original data was collected, and finally the grey correlation analysis was applied to the demand weight calculation. The specific calculation steps were as follows:

Initial value: the reference number of the dependent variable was listed as the benchmark vector sequence, denoted as $x_o\left(k\right)$. The reference number of the independent variable was listed as a sub-sequence, denoted as $x_i\left(k\right)$, and the original data was dimensionless.

$$x_i^{'}\left(k\right) = \frac{x_i\left(k\right) - \min x_i\left(k\right)}{\max x_i\left(k\right) - \min x_i\left(k\right)} \quad (1)$$

i represents the serial number of scoring expert, and $x_i\left(k\right)$ refers to the set of scoring experts for each usability requirement.

Equalization: the absolute value of the difference between each subsequence and the benchmark vector sequence at each point was calculated, and then the maximum and minimum difference sequences were obtained.

$$\triangle_i\left(k\right) = |x_i'\left(k\right) - x_i\left(k\right)|, \triangle_i = \left(\triangle_i\left(1\right), \triangle_i\left(2\right), \cdots, \triangle_i\left(n\right)\right), \quad i = 1, 2, \cdots, m \quad (2)$$

$\triangle_i\left(k\right)$ represents the absolute value of the difference between the subsequence and the benchmark vector sequence.

Calculation of the correlation coefficient: the data of absolute value points were obtained, and the correlation coefficient of each absolute value point was calculated according to formula (3).

$$\gamma_{0i}\left(k\right) = \frac{m + \varepsilon M}{\triangle_i\left(k\right) + \varepsilon M}, \varepsilon \in (0.1), k = 1, 2, \ldots, n; i = 1, 2, \ldots, m \quad (3)$$

$\gamma_{0i}\left(k\right)$ represents the relative difference between the subfactor and the parent factor at the point k, and the resolution coefficient ε is usually 0.5.

Calculation of correlation degree: the average value algorithm was used to calculate the correlation degree γ_{0i}, and formula (4) is used to achieve the correlation coefficient of each requirement.

$$\gamma_{0i} = \frac{1}{n}\sum_{k=1}^{n}\gamma_{0i}(k), i = 1, 2\ldots, m \tag{4}$$

Competition demand correlation coefficient: after the availability demand correlation coefficient was calculated, the importance of competitive demand was also calculated by the same calculation method. The results could be seen from Table 1.

Table 1. Demands correlation.

Demand	UR1	UR2	UR3	UR4
User demand correlation ei	0.513	0.667	0.539	0.572
Competitive demand correlation degree wi	0.644	0.587	0.556	0.587

From the calculation results, it can be seen that the user demand e_i and competitive factors w_i.

$$p_i = e_i \times w_i, i = 1, 2, \ldots, m \tag{5}$$

According to formula (5), the importance pi of availability requirement was UR1 (0.331), UR2 (0.392), UR3 (0.299) and UR4 (0.336). The order from high to low was:

UR2 (efficiency) >UR4 (user satisfaction) >UR1 (validity) >UR3 (reliability)

Design Elements of Intelligent Ultra-Cryogenic Refrigerator

Unlike traditional products, intelligent interactive products have three elements: form, function, and interaction. The optimal configuration of form and function elements are determined by user's interactive experience. Form elements include colour, material, etc. of traditional products; functional elements gradually extend from physical attributes of traditional products to user-centred emotional attributes; interactive elements as unique elements of interactive products, which include the design of software and hardware between human-computer interactions, are important factors affecting user satisfaction. The interaction among the three is manifested as follows: (1) form elements provide users with behavioural semantic information, which is a function in itself; (2) form follows behaviour, and behavioural interaction realizes product functions; (3) functional configuration influences interaction mode and form characteristics.

Functional Elements

Product functional elements include basic functions and interactive functions. Whether functional elements are properly allocated directly affects product availability. The basic function of intelligent ultra-cryogenic refrigerator is to keep the samples in ultra-low temperature environment by cooling, and the interactive function includes intelligent interaction, temperature control, selection and so on. Refrigeration is a necessary condition for the normal operation of the machine, which is not included in the research of product availability. Interactive functional elements can be divided into intelligent guidance, temperature display, selection of freezing storage boxes, high and low temperature alarm, and other functions according to user needs, as shown in Table 2.

Table 2. Usability functional elements of intelligent ultra-cryogenic refrigerator.

Functional Elements	Temperature Control	Alarm Function	Intelligent Interaction	Selection Function
1	Temperature regulation	High and low temperature alarm	Intelligent guidance	Optional network
2	Temperature record	High and low voltage alarm	Statistical data	Selection of frozen storage shelves
3	Temperature display	Alarm for heat dissipation difference of condenser	Search function	Selection of frozen storage box
4		Alarm of ambient temperature exceeding standard		Selection of liquid nitrogen standby system
5		Power off alarm		

Form Elements

Form elements (as shown in Table 3) provide users with effective behavioral semantic information. Reasonable arrangement of form elements can optimize interaction performance.

Table 3. Usability form factor of intelligent ultra-cryogenic refrigerator.

Form elements	Product Appearance	Product interior	Operating interface	Display interface
1	Appearance shape	Spatial segmentation	Button size	Size
2	Overall dimensions	Spatial dimensions	Button shape	Layout
3	Structural distribution	Size and distribution of freezing shelf	Button distribution	Typeface
4	Local proportion	Information interface of sample box		Color
5	Appearance color			Style
6	surface texture			

Interactive Technology Elements

Interactive technology elements are mainly divided into electrical control technology and display control technology, as shown in Table 4. Temperature control technology is the safety guarantee of sample cryogenic storage, which can effectively enhance the reliability of the product; defrosting control technology directly affects the clarity of the interface of sample drawer, avoids the interface condensation frost caused by temperature fluctuation, and reduces the user's operating performance; sensing technology is equivalent to the product's sensory system, which is an important medium for good communication between human and machine. Interface interaction technology directly affects users' emotional experience and subjective satisfaction.

Table 4. Usability interactive technical elements of intelligent ultra-cryogenic refrigerator.

Technical Elements	Electrical control technology	Display Control Technology
1	temperature control	Sensing Technology
2	Defrosting control	Interface Interaction Technology

Relevance Solution of Availability Requirements and Design Elements

Combining the usability design elements, three experts in the field of usability research were invited to grade the degree of influence to product design elements on demand from 9 (the degree of influence is very obvious) to 1 (the degree of influence is not obvious), and the original data were collected. The grey relational analysis method was used to match product design elements with usability requirements, and then the design elements under the mapping of usability requirements were obtained, as shown in Table 5.

THE KEY INDICATOR SYSTEM OF INTELLIGENT ULTRA-CRYOGENIC REFRIGERATOR DESIGN

The key indicators are designed to provide decision-making basis for product design process and optimize the allocation of quality factors driven by user needs, so as to improve the availability of products.

The key indicator system includes the general target layer, usability requirement layer, design elements layer and index layer, as shown in Figure 4. The relationship among the total target layer, usability requirement layer and design elements layer is a gradual hierarchical relationship, and the specific interpretation function of design elements layer is undertaken by the index layer. In order to construct the key index system for the availability of intelligent ultra-cryogenic refrigerator, the order relation analysis method should be applied to calculate the weight of each index and determine its priority order. From the usability requirement weight calculation, we can see that UR2 > UR 4 > UR 1 > UR3. Efficiency (UR2) is the most important and priority user requirement in the usability design of intelligent ultra-cryogenic refrigerator. Therefore, the index under efficiency (UR2) will be taken as an example to prioritize in the following section, as shown in Table 6.

Ten industry experts were invited to rank the indicators of each design element in the mapping of usability demand layer, and the order relation analysis method was applied to calculate the index weight. Take the calculation process of expert 1 as an example.

Known importance sorting E1 > E5 > E3 > E2 > E6 > E4, and translated into E1' > E2' > E3' > E4' > E5' > E6', namely the weight $W_{E1} = W_{E1'}$,

Table 5. The relationship between usability requirements and design elements.

Number	Effectiveness (UR1)	efficiency (UR2)	reliability (UR3)	User Satisfaction (UR4)
1	Overall dimensions	Intelligent guidance function	Temperature display	Appearance shape
2	Structural distribution	Internal spatial Segmentation	Temperature record	Local proportion
3	Operating interface button size	Internal space size	High and low temperature alarm	Appearance color
4	Operating interface button shape	Size and distribution of freezing shelf	High and low voltage alarm	surface texture
5	Button distribution of operating interface	Sample box information interface	Alarm for heat dissipation difference of condenser	Display interface font
6	Display interface size	Display interface layout	Alarm of ambient temperature exceeding standard	Display interface color
7	Temperature regulation function		Power off alarm	Display interface style
8	Statistical data function		Selection of liquid nitrogen standby system	
9	Search function		Temperature control technology	
10	Selection of frozen storage box and function of frozen storage box shelf		Interface interaction technology	

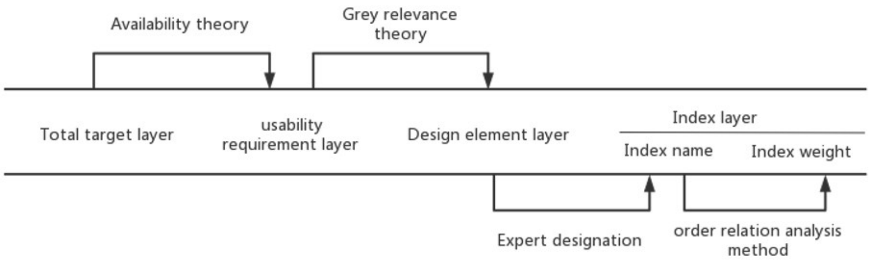

Figure 4: Product usability design key indicator system framework.

$W_{E5} = W_{E2'}$, $W_{E3} = W_{E3'}$, $W_{E2} = W_{E4'}$, $W_{E6} = W_{E5'}$, $W_{E4} = W_{E6'}$. The assignment table 5 identifies r_1, r_2, r_3, r_4, r_5.

$$w_n = \left(1 + \sum_{k=2}^{n} \prod_{i=k}^{n} r_i\right)^{-1} \quad (1)$$

$$w_{k-1} = r_k w_k (k = n, n-1, \ldots 3, 2) \quad (2)$$

Table 6. The key indicator system of intelligent ultra-cryogenic refrigerator design.

Overall target layer	Availability requirements layer	Design element layer	Indicator name	Number
The key indicator system of intelligent ultra-cryogenic refrigerator design	Efficiency (UR2)	Intelligent guidance function	Whether the intelligent guidance function is appropriate	E1
		Internal space division	Whether the internal space division is appropriate	E2
		Internal dimension	Whether the internal space size is appropriate	E3
		Size and distribution of freezers	Whether the size and distribution of freezers are reasonable	E4
		Sample box information interface	Whether the interface information of the sample box is clear	E5
		Display interface layout	Display interface layout is easy to understand	E6

According to formula (1) and (2), we can get: W_{E1}=0.18, W_{E2}=0.13, W_{E3}=0.13, W_{E4}=0.13, W_{E5}=0.22, W_{E6}=0.22. Calculate the average value to determine the weight of efficiency:

$$E1 > E6 > E5 > E2 = E4 > E3$$

It could be seen from the index weight calculation that the intelligent guidance function could significantly improve the use efficiency of the product. Therefore, it could be seen that the intelligent guidance function was the key index of the usability design of the intelligent ultra-cryogenic refrigerator, which conforms to the logic of user operation behaviour, helped users quickly and accurately located the sample storage location, efficiently completed interactive tasks, and optimized interactive performance.

CONCLUSION

With the rapid development of modern medical industry and industrialization, intelligent ultra-cryogenic refrigerator, as the key equipment for cryogenic storage of biological samples or special workpieces, has been widely used. It is of great significance to speed up the level of medical research and promote industrial development. With the massive implantation of information technology and chips, the performance and operation of products are becoming more and more complicated, which does not match the user's cognitive and behavioural logic, and greatly decreases the availability of products. Therefore, in order to meet the needs of industrial development, it is particularly important to evaluate its usability and optimize its product performance. This paper firstly systematically analysed the usability behavioural logic of intelligent ultra-cryogenic refrigerator, and deeply analysed its usability requirements. Then, by combining with usability related indicators, the usability requirements were matched with product design elements, after that grey correlation and sequence analysis method were combined to calculated the weight. The extraction of ultra-cryogenic refrigerator usability design key indicator-intelligent guidance would help users quickly and accurately find the location of the samples to store and complete tasks efficiently, ensure the stability of the samples, conform to the user's behaviour logic, effectively improve the usability of products, and create the interaction-mixing-symbiosis mode between human and intelligent machines.

ACKNOWLEDGMENT

This paper supported by the 2020 Humanities and Social Science Research Foundation of Ministry of Education of China, Title: Research on the Design Strategy of Elderly Products Based on Sensory Compensation (20YJA760101). In addition, P. Zhang thanks to our dear friend Xiaomin Ding, always remember the contribution of her.

REFERENCES

Alan Cooper, Robert Reimann & David Cronin. (2012) About face 3 The Essence of Interaction Design. Liu Songtao (Trans.). Beijing: Publishing House of Electronics Industry.

Li Yongfeng & Zhu Liping (2012). Product usability evaluation method based on Fuzzy Analytic Hierarchy Process. Journal of Mechanical Engineering (14), 183–191.

Liu Long & Liu Huchen. (2010). Product Usability evaluation method using FMEA. Industrial Engineering Journal (03), 47–50.

NIELEN J.k. (2004). Usability Engineering. Liu Zhengjie (Trans.). Beijing: China Machine Press, 2004: 16–24.

Ronggang Zhou & Alan H. S. Chan. (2016). Using a fuzzy comprehensive evaluation method to determine product usability: A proposed theoretical framework. Work (1). doi:10.3233/WOR-162474.

Su Jianning, Liu Tingting & Wang Peng. (2016). Research on Usability Evaluation of Product Form Design Based on Naïve Bayes Method. Journal of Machine Design (02), 105–108. doi: 10.13841/j.cnki.jxsj.2016.02.021.

Xin Xiangyang. (2015). Interaction Design: From physical logic to behavioral logic. Art& Design (01), 58–62. doi: 10.16272/j.cnki.cn11-1392/j.2015.01.012.

Zeng Dong & Chen Yaming. (2008). Evaluation System of Product Appearance Design Based on Usability. Packaging Engineering (01), 137–139+164.

Zhang Lin & Zhao Jing. (2015). Visualization of User Requirements in Product Design. Journal of Machine Design (7), 126–128. The doi: 10.13841/j.carol. carroll. nki. JXSJ. 2015.07.028.