Research on User Mental Model Acquisition Based on Multidimensional Data Collaborative Analysis in Product Service System Innovation Process

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Abstract. The core of innovation design for product service system is to provide products and services meeting the needs of users. Traditional user research methods have many drawbacks, such as data interference, fuzzy feedback, single-dimensional indicators lack mutual verification, these issues have not been effectively resolved. If the designer can't understand the users' needs in time and objectively, and accurately construct the users' mental model, it will make the design decision blurred and slow, and the design scheme lacks the utility. Taking into account the drawbacks of traditional user research methods, we use the multidimensional data collaborative analysis technology to obtain user, environment, tasks and other context information. The interaction between the user and the product service system is selected, and the context data of the target user is acquired by using the wearable device, the eye movement measurement and behavior analysis system. These methods can assist the designer discover the product service system usability problem, understand the users' needs, build the users' mental model. This paper focuses on the research of user mental model acquisition mechanism in Product Service System Innovation Process. Based on context awareness multidimensional data collaborative analysis, the users' mental model is constructed accurately. To promote the effective matching between the design conceptual model and the user mental model to produce the optimal design, avoid the waste of the design process resources.

Keywords: Product service system · User needs · Mental model · Context awareness · Multidimensional data · Collaborative analysis

1 Introduction

Traditional enterprises are committed to providing tangible products for the people, resulting in a large number of energy wastes in the production, sale, use, recycling process. It also causes a shortage of resources, environmental pollution and other serious problems affecting people's daily lives. With the increasingly serious environmental problems, there is an urgent need to change the traditional product design. The designer

D. Harris (Ed.): EPCE 2017, Part II, LNAI 10276, pp. 35–44, 2017.
DOI: 10.1007/978-3-319-58475-1_3

should research sustainable innovation design mechanism which takes into account the needs of users, environmental benefits, social benefits and enterprise development. Product Service System (PSS) is a kind of innovation strategy change under the social sustainable development target [1]. Product service system provides products and services to users. With the rapid development of information technology, tangible products are gradually weakening, product service system presents intelligent and non-material characteristics. The users of Product service system are not only ordinary users, but also disabled, the elderly, children and other primary users. Users, especially the primary users can't be good use of the products and services when they face to dematerialization, information technology and high-tech products service system provided by the enterprise. It will produce a negative user experience when the products and services provided by enterprises can't meet the user needs. Users will eventually abandon the product service system, resulting in waste of design and service process. these presents a huge challenge to designers. Users will generate awareness and unconscious expectations in the process of interaction with product service system, forming a user mental model. Designers change the inherent psychological image into a product service system external form, forming a design concept model [2]. If the designer can't understand user needs and accurate construct the user mental model, it will make design decision-making ineffective. How to obtain the characteristics of users' needs accurately and construct the users' mental model in the process of product service system innovation is the main problem to be solved.

The context of User interaction with the product service system is changing at any time, which impacts the user physiological and psychological, so the designer should consider user needs in a more specific context. Schilit [3] classifies the context as locations, identifications of persons and objects, and changes in these objects. In the process of using product service system, the context data form multi-dimensional space, and there is regularity and correlation between data. The designer can be more intelligent, real-time, accurate access context information Based on context-aware technology in the process of user interaction with the product service system. Designers can objectively understand the context status of the users, find usability issues, mining user needs and build user mental model. The results of this research will provide reference methods for designers to miming users' needs, improve the efficiency and effectiveness of design decision, and to provide more personalized service.

2 Related Works

2.1 User Knowledge and Design Knowledge

User knowledge includes the users' physiological, psychological, cognitive, behavior, social knowledge. Design knowledge includes the designer's experience, thinking, design process and product function, material, shape, i.e. [4, 5]. In the process of design innovation, the user information data is acquired through the scientific research methods, the user mental model is constructed according to the user knowledge and reasoning rules as well as the user knowledge interpretation. Through the users' knowledge acquisition, analysis, reasoning to map the users' mental model to the functional model

and the program model, iterative optimization design program [6, 7]. by this method, the designer can promote the transformation of user knowledge to product knowledge effectively, and finally match the design conceptual model and user mental model effectively to achieve sustainable product service system innovation.

2.2 Mental Model

Psychologist Kenneth Craik [8] first proposed the concept of mental model in 1943. Donald Norman [2] introduced the concept of mental model into the design field, and proposed three models in the design field, namely, system model, design concept model and user mental model.

The design concept model focuses on the designers cognitive understanding things in the creation process. User mental model understand interrelation and Interaction process between the user and product or system. The system model takes into account the overall interaction model and the law of things to run. Mental model help people to discover the laws of things and understanding new things or information, then guide people to deal with various relationships. We can explore the formation process of the mental model in the process of using product service system, that is, how the users form the expectation of consciousness or unconsciousness to the existing product service system according to the knowledge, experience and context. Mental model can also help designer to understand users' perception process and interpretation process when they use product service system, that is, how users perform feature recognition, matching and meaning of activation to design program with prior knowledge.

2.3 The User Research Methods Based on Mental Model Representation

It is important to obtain the user mental model accurately for making a design decision. The user research methods based on mental model representation mainly applied to user domain research of product service system. The methods include Questionnaire method, Interview method, Observation method, Think-aloud method, concept map, Card Sorting. i.e. the designers can understand aimed users' psychological need and construct users' mental model by these methods.

Delugach et al. [9] described a method of direct acquisition of team mental models in the form of conceptual graphs which applied a knowledge capture approach and a supporting graphical tool. S. Angsupanich and S. Matayong [10] developed the prototype of blinds' mobile application. They applied the interview method to obtain the blind user mental model in the process of Product Innovation. E. Kowalczyk and A. Memon [11] applied the GUI testing method to obtain the user mental model. they verified the effectiveness of GUI testing methods by comparing the two mental models of 12 Android apps – one derived from the app's usage and the other from its public description. Lorraine Normore and Vandana Singh [12] described a preliminary study of application to support the user-centered design of future information and communication technologies. A. Pentel [13] applied Think-aloud protocol to connect user emotions and mouse movements. A. Nawaz [14] presents how the choice of card sorting techniques affected the results of the information structure for websites.

These methods are easy to operate, However, there are many subjective elements in questionnaire, interview and observation, which affect the accuracy of the analysis results. Think-aloud method is easy to increase the users' psychological burden. Card Sorting based on the content rather than the task, it is not suitable for the users' real context, which may lead to the analysis results are not accurate enough. Concept mapping needs to refer to specific research objects and contexts, it is not suitable for applying to cognitive information with ambiguous levels or Different styles.

2.4 The User Research Methods Based on Physiological Measurement Data

User research based on physiological measurement data, such as Skin electrical, ECG, EEG, i.e. which help designers to gain a deeper understanding of user experience and internal cognitive processing mechanism in the process of using product service system [15]. Masaki et al. [16] quantified evaluated the software experience using EEG. Mauri et al. [17] revealed that using Facebook could evoke a psychophysiological condition characterized by high valence and high arousal. They used some methods including skin conductance, blood volume pulse, electroencephalogram, electromyography, respiratory activity, and pupil dilation. Ge et al. [18] studied the application and future research prospects of electrophysiological parameters such as skin electrical, ECG and EEG in user experience research. Electrophysiological Technique may apply in the design of products and services such as helping the disabled, medical care and intelligent driving in future. The signal is easily influenced by external environment, physical activity and psychological stimulation when we measure the users' physiological signals, it may interference with accuracy of the data results

2.5 The User Research Methods Based on Eye Movement Experiment

The user research based on eye movement experiment is widely used in the design process of products and services, which is mainly used in the study of consciousness and unconscious demand, usability testing process. Chen et al. [19] developed different 3D animations fostered students to generate better learning performance and sophisticated mental models. They also used eye movements to evaluate users' mental model. Li et al. [20] proposed a method for user requirement acquisition based on eye tracking. Lai Meng-Lung et al. [21] revealed how eye tracking technology was used for learning study. There are also some problems in eye movement experiment, such as user eye movement trajectory can't completely reflect the true idea of the user; it is difficult for researchers to distinguish clearly internal factors simply according with the eye movement data; when the number of users is small, eye movement results may vary greatly. Thus, a single experiment using eye movements to obtain experimental results may have deviations or errors.

2.6 The User Research Methods Based on Virtual Reality Technology

User research based on virtual reality technology can be used to study user needs, function and program evaluation of product service system. And we can understand the users'

experience and behavior more realistically with virtual reality technology. Virtual reality system has been developed and applied in the design, training and ergonomic evaluation applications. Kuliga et al. [22] suggested that virtual reality is a potential practical tool for supporting behavioral validation in psychology, architectural research, and future research. F. Meng and W. Zhang [23] simulated a fire emergency with virtual reality technology and studied the pathfinding behavior in a fire accident. Otebolaku and Andrade [24] explored and evaluated the context-aware smartphone application and recognition classification algorithms. Dong et al. [25] explored the user experience and assessment of context-aware smart home based on virtual reality research methods. There are also some problems in the actual use of virtual reality, such as expensive, poor platform compatibility, which affect the wide application of virtual reality technology in product service innovation. In the process of experimental research, various data acquisition methods have different characteristics.

User psychology is often affected by environmental, task, physiological, psychological, social experience and other context factors. In the design process, the designer should consider a variety of factors in the process of using product service system, explore user behavior, motivation and demand in-depth, accurate obtain user mental model, design the function and program of product service system to avoid invalid design process and useless product service system.

3 Acquisition of User Mental Model Based on Multidimensional Data Collaborative Analysis in Product Service System

The development of Internet of Things technology makes it more convenient to obtain the experimental data. Designers can understand the user context more objectively, accurate mining user mental model based on the multidimensional data collaborative analysis method. At the beginning of the experiment, we first select the target user and build context scenarios. Then we obtain the users' electroencephalogram (EEG), electrocardiogram (ECG), Skin electricity, electromyogram (EMG), respiration, heart rate, pulse and other physiological data in real time through a variety of sensor devices. Through WIFI, GPS technology, light sensors and other physical sensors, we obtain environmental light, noise, temperature, location and other environmental context data. Through the behavior analysis system, we obtain the users' action and behavior data.

The multidimensional data are huge and complex, and the data contains many invalid data, such as noise and outliers, data duplication and missing. We remove the noise and irrelevant data in the data set by data cleaning, and analyze the law of the data itself and the correlation among the data. We simplify the data and find the useful feature to reduced data size and amount of data as much as possible. We mining, calculate and analyze the multidimensional large-scale data. We obtain the user characteristics through clustering, association, artificial neural network and visual analysis. The clustering algorithm gathers the data with same characteristics together. It can help designer find product availability problems and Mining personality or common features. The association rule mining model will acquire the interdependence and correlation of different dimension data, and discover the association

rule, correlation or causal structure through algorithm. We can find the data hidden rules, mining user needs, obtain user mental model by these methods.

4 Acquirement of Elderly User Mental Model in the Process of Using Intelligent TV Product Service System

The aging of the modern society is becoming increasingly serious, the proportion of the elderly population continues to grow. "2015 World Population Prospects" shows that in 2010, the world's age population of 65-year-old and over 65 years is about 538 million, accounting for 8% of the world's total population. By 2050, the number of people aged 65 years and over 65 years will reach 1.5 billion, accounting for 16% of the world's total population. The increase older population has driven the development of a silver economy dedicated to the provision of goods and services for the elderly. With the development of information technology, modern products and service systems have more high-tech features. Product service system is change from the passive service which the user makes a service request to the predictive, perceptual, emotional smart service. Products with good availability service system will give the elderly a pleasant experience and provide human services to elderly. In the process of using the product and service, Elderly users will form the mental model of product service system due to the limitation of experience, knowledge and other factors, as well as physiological and psychological factors. If the designer can't accurately obtain the elderly users' mental model, it will make the design concept model and user mental model can't effectively match, leading to poor availability of product service system. The elderly user is not easy to understand and operate, which affect the efficiency of task completion, trigger the frustration of older users and form negative experience (Fig. 1).

Fig. 1. Mental model measurement of elderly users in real family context

We obtained the older users' emotion state when they watched smart TV in the real home environment through experimental methods. We used the Changhong 50Q3T smart TV models to set the experimental context. We Selected 30 elders aged from 55 to 75 years old to obtain their mental model for level search and Pinyin search TV program by simultaneous measurement their physiological, psychological and behavior

data. We obtained the following data from a variety of sensor devices: the elders' physiological data including ECG, skin electrical, EMG, breathing, heart rate, pulse and other physiological data. Environmental date was including light data, temperature data and other environmental data. There were also the elders' behavior and activity data in the implementation of the task. We also obtained the elders' facial expression data through a behavior analysis system (Fig. 2).

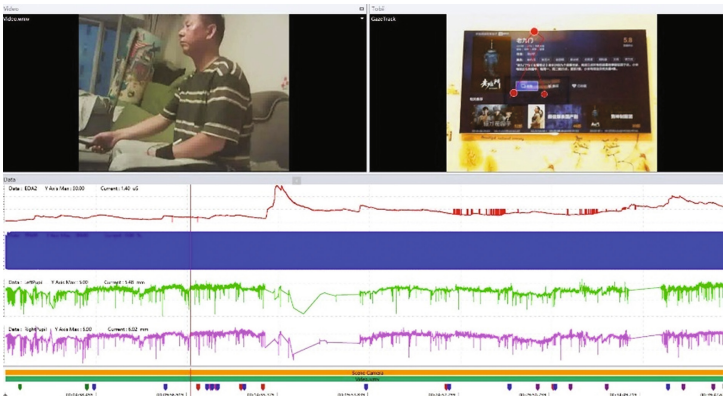

Fig. 2. Multidimensional data acquisition of smart TV for elderly

In this part, the project team analyzed the acquired physiological signals and emotional data, corrected and cleaned up the acquired error data, and converted the multi-source heterogeneous data into computable processed data form. In the algorithm, we mainly used clustering and classification algorithms. Cluster analysis is composed of several patterns. Normally, a pattern is a vector of measurements, or a point in a multidimensional space. Clustering analysis is based on similarity, it has more similarity between patterns in a cluster than patterns that are not in the same cluster. Clustering analysis algorithm is divided into partitioning method, hierarchical method, density-based method, grid-based method. The classification algorithm finds the classification rule by analyzing the training set of the known category, and predicts the classification of the new data. The single classification method mainly includes: decision tree, Bayesian, artificial neural network, K-nearest neighbor, support vector machine and classification based on association rules.

Through the study, we find that most (about 70%) of elderly users have high HF (parasympathetic activity) and low LF (sympathetic activity) in the process of pinyin search. They also have relatively high LF (sympathetic activity) and relatively low HF (parasympathetic activity) in the process of level search. Behavioral data analysis shows activity characteristics for a user to complete a search task with two different search methods. The experimental data show that the average time for a user to complete search task with a level search is significantly less than the average time for a pinyin search. By observing the expression and behavioral characteristics of older users, we find that older users often have frustration emotion in the process of using pinyin search. These multidimensional data indicate that the user experience

of level search is superior to pinyin search. The current TV remote control pinyin input model is different from older users' mental models. Some older people with lower educational levels affect their pinyin input search operations. In addition, older users' poor vision and slowly behavior make pinyin search more difficult. We also make interviews with older users, most older users tend to operate a simple hierarchical search approach. Some older users have suggested that they want simpler or smarter programs to search, such as voice search. But in the process of using voice search, the obstacles arising mainly from the voice isn't standard, it may affect voice search function.

The elderly perception, cognitive and physiological functions showed a downward trend with the increase of age. Elderly vision decline, hearing dropped, behavioral delay, the ability adaptability to various environments gradually weakened, these features highlight the usability problems of product service system. The designer can objectively understand the psychological needs of older users through multidimensional experimental data analysis. They should design product service system easy to use and provide more convenient services to elders.

5 Conclusions

We propose a method for acquiring user mental models based on multidimensional data synchronization analysis. In the process of product service system design, the designer access to the users' mental model objectively and accurately, they should take into account the users' various context factors. By using a variety of sensors, eye tracking and behavior analysis as well as interview, designer can obtain users' multidimensional data information objectively and analysis users' mental model. Through the design knowledge acquisition and reasoning, the mapping relation between the user mental model and the design conceptual model is established, and the iterative optimization design scheme is realized. Finally, the effective match between the user mental model and the design conceptual model is achieved, and the optimal product service system design meeting the user demand is produced.

The multidimensional data collaborative analysis method is applied to the innovative design process of the product service system. It can help designer produced reasonable design schemes to meet the physiological, psychological needs and context characteristics of the users, avoid the waste of resources caused by the unreasonable design schemes. This has certain value for sustainable innovation design theory and product service system design practice.

Acknowledgements. We would like to thank Kingfar International Inc and Qingju Wang, Guoqiang Sun, mengda Yang support our experimental data acquisition. We also thank Ministry of Education Humanities and Social Sciences Research Youth Fund Project and Grant No. 15YJCZH034 that partially supported our research work.

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