

Title	CPS技術統合による感性評価の研究—インタラクティブ・コスチューム・デザインの事例
Author(s)	王, 偉珍
Citation	
Issue Date	2019-03
Type	Thesis or Dissertation
Text version	ETD
URL	http://hdl.handle.net/10119/15780
Rights	
Description	Supervisor:永井 由佳里, 先端科学技術研究科, 博士

Doctoral Dissertation

**Toward the Integration of Cyber-Physical
Systems with Emotional Evaluation:
A Perspective on Interactive Clothing Design**

WANG Weizhen

Supervisor: Professor Yukari Nagai

Graduate School of Advanced Science and Technology

Japan Advanced Institute of Science and Technology

Knowledge Science

March, 2019

Abstract

Keywords:

Interactive Clothing, Cyber-Physical Systems (CPS), Cyber-Physical-Clothing Systems (CPCS), Evaluation, Design

Revolutionary changes have been occurring at an unprecedented rate in the fields of clothing. The interactive clothing, a topic on which there is little previous research, an evolutionary branch of smart clothing in the field of information science, which emphasizes the function of social symbols that mutual interaction or communication between the wearer and their environment based on the integration of information science and traditional clothing. Combining CPS with a clothing engineering design to input a certain physical signal into clothing, the interactive clothing can output a certain social symbol that people or clothing environment can perceive and generate corresponding interaction. This kind of social symbol is the expression form of the interactive clothing as the interactive medium for people to interact with the environment. With the gradual integration of the internet of things (IoT) and CPS into people's daily life and the growing development of smart textile technology, interactive clothing will play an increasingly important role in future interpersonal communication and interaction.

Despite its impressive track record in smart clothing research and development, we still have to confront with several current research dilemmas or development bottlenecks from correlative humanities science and information technology respectively. Researchers have generally focused on high-tech approaches to implementing smart clothing design with multifunction. Nevertheless, the complex sociological attributes of clothing, i.e., its interactive symbolism and properties of emotional expression, design hierarchy and design aesthetics and other aspects should not ignore.

The overall purpose of this research is to bridge the gap between CPS applications in the field of information science and emotional evaluation in the field of humanistic science, to minimize the unbalance between humanistic emotion and wearable smart technologies for interactive clothing innovation, to investigate how the transformation could realize from information to knowledge in the process of interactive clothing design, to establish a basic framework of design principle and design evaluation criteria system for interactive clothing, and suggest practical implication for interactive clothing design.

To attain the above objectives, the study will answer one Major Research Question: What happened to the interactive clothing when the social semantics of transform from the information stage to the knowledge stage in the architecture of CPS? In addition, three Subsidiary Research Questions (SRQ), according to Soft System Methodology, i.e., the “WHY”,

“HOW” and “WHAT” as follow. SRQ1: Why does the R&D of interactive clothing worn in daily life need to integrate smart technology with emotional design and humanistic evaluation simultaneously? SRQ2: How is the technology transformation could realize between the signals in the field of information physics and the symbols in the various dimensions of humanity and society? SRQ3: What does the design principles of interactive clothing should be valued in the context of CPS’s growing prosperity?

The practical research of this topic was started in 2012; progressive results were getting during three stages. The first stage was in 2013, two types prototype of infant’s smart clothing were developed. As a result, two of China’s utility model patents have granted, which illustrates the feasibility and rationality of this study’s entry point. The second stage is the interactive couple clothing prototype, which is a kind of clothing media that can transfer some interpersonal relationship, completed in 2016-2017. Further, the diversified interaction results have achieved through a three-piece set of interactive parent-child clothing prototype in the third stage from 2017.

In theoretical research, by literature review and literature integration approaches, the psychology, sociology and design hierarchy of clothing, as well as data-information-knowledge-wisdom (DIKW) theory and CPS architecture are deduced and summarized from the perspective of humanities and technology respectively to analyze the humanistic and technical attributes of interactive clothing. The CPCS model of the technical development process of interactive clothing is created, and the validity of the CPCS model is verified by the method of prototype development and Kansei engineering evaluation. Through Kansei evaluation, the design elements and evaluation criteria of interactive clothing are also extracted. The results found that the research on interactive clothing should integrate the two opposing perspectives of humanities and technology, and bridge their gap from an interdisciplinary perspective in the process of prototyping and evaluation.

The main differences between the contents of this study and previous studies by other scholars are as follows: (1) New prospective, that is, this study pioneered a new field of smart clothing research, namely interactive clothing; (2) New approach, that is, this study introduces CPS technology into clothing development from the approach of art design; (3) New system, that is, a research framework for interactive clothing was initially established.

The main original contributions of this study are as follows: (1) The concept of interactive clothing was pioneer defined; (2) From the perspective of humanities and technology respectively, the models of studying the attributes of interactive clothing are built to guide the research path; (3) Integration of CPS, DIKW and other information technology and theory to create a Cyber-Physical-Clothing Systems architecture model to guide the prototype development of interactive clothing ; (4) The 18 “C” Design Principles of interactive clothing are revealed; and (5) The criteria framework of interactive clothing design evaluation is created to encourage the object of evaluation to develop in the right direction and objectives. Therefore, the knowledge framework associated with interactive clothing is preliminarily established in the category of Knowledge science.

Acknowledgments

It would not have been possible to write this doctoral thesis without the help and support of the kind people around the author, to only some of whom it is possible to give a particular mention here.

First of all, the author wishes to express his sincere gratitude to his supervisor Professor Yukari Nagai of Japan Advanced Institute of Science and Technology for her constant encouragement, inspiring instruction and patient guidance throughout this research endeavor and life in Japan.

Second, the author would like to express his heartfelt gratitude to his second supervisor Associate Professor Takaya Yuizono, and Professor Masami Maekawa as well as Sensei Jader Zelaya and Yabuuchi Kumi who have instructed and helped a lot in the past years.

The author would like to thanks to Professor Ayumi Yasui, Professor Kazunori Miyata, and Associate Professor Rihyei Kang for their technical expertise and dedicated support, who give him insightful comments on his research. The author also would like to thank Professor Xu Dong of Tianjin Polytechnic University and Professor Tsutomu Fujinami of Japan Advanced Institute of Science and Technology, which help the author to complete his minor research.

The author also much indebted to the professors and teachers of the Knowledge Science School, the author benefited a lot from their wonderful courses.

Besides, the author takes this opportunity to express most sincere gratitude to his family, who gives him great love and fully understanding through all these years, which is his strongest motivation to continue his study and pursue his life goals. The author and his wife studied at Japan Advanced Institute of Science and Technology together, and their daughter also studied in primary school in Japan. Study together in Japan and work together along the goals. In particular, this paper dedicate to his father in heaven who gave the author an eternal incentive for academic research.

Last but not least, the author wishes to appreciate all members of Prof. Nagai's lab for their help and cooperation.

Table of Contents

Abstract	i
Acknowledgements	iii
List of Figures	vii
List of Tables	ix
Chapter 1	
Introduction	1
1.1 Background.....	1
1.1.1 Research subject.....	2
1.1.2 Definition of interactive clothing	4
1.1.3 Research ideas and methods.....	5
1.1.4 Academic and industry research background	6
1.2 Existing problems and research motivations	12
1.3 Research aims and objectives	16
1.4 Research question	17
1.4.1 Major research question	17
1.4.2 Subsidiary research questions	17
1.5 Significance of the study.....	18
1.5.1 Theoretical and academic level	18
1.5.2 Industrial level.....	18
1.5.3 Application level	19
1.5.4 Product design and development method level.....	19
1.6 Structure of the dissertation	19
Chapter 2	
Literature Review, Definition and Deduction	22
2.1 The social psychology and semiotics of clothing	22
2.1.1 Symbolic semantics of clothing	22
2.1.2 The inference and representation symbols of clothing.....	23
2.2 The relationship between clothing needs and Maslow’s hierarchy of needs	24
2.2.1 Maslow’s hierarchy of needs.....	24
2.2.2 Enlightenment of Maslow’s theory on clothing demand	26
2.2.3 The relationship between Maslow’s hierarchy of needs and clothing needs ..	28
2.3 The hierarchy and typology of clothing design	29
2.4 Deduce the evolution trend of interactive clothing—IoC	31

2.5 The relationship between DIKWS and the evolution of clothing function.....	34
2.6 The relationship between CPS/IoT and clothing	36
2.6.1 Concept of the IoT.....	36
2.6.2 Concept of the CPS	36
2.7 Other associated terminologies.....	38
2.7.1 Technology-centered design and human-centered design.....	38
2.7.2 Emotional design.....	39
2.7.3 Kansei engineering.....	39
2.8 Summary.....	40
2.8.1 Interactive clothing conforms to the evolution trend of clothing	40
2.8.2 Humanistic and technical features of interactive clothing	41
Chapter 3	
Research Model and Methodologies	44
3.1 Research roadmap.....	44
3.2 Creating the CPCS research model.....	45
3.2.1 Technical processing of interactive clothing at the physical level	45
3.2.2 Technical processing of interactive clothing at the cyber level.....	47
3.2.3 Technical processing of interactive clothing at the social level	47
3.2.4 Technical processing of interactive clothing on the cross-level structure	48
3.3 The definition of research methods.....	49
3.3.1 Practice validation and prototyping methods	49
3.3.2 Prototype evaluation method.....	49
3.3.3 Model inductive method.....	49
3.4 Summary.....	51
Chapter 4	
Prototyping of Interactive Clothing.....	52
4.1 Case study 1, smart infant clothing.....	52
4.1.1 An infant's crotch humidity monitoring alarm trousers	52
4.1.2 Temperature monitoring infant clothing.....	54
4.2 Case study 2, interactive clothing for couples	56
4.2.1 Determining the categories of experiential prototype	56
4.2.2 Purpose, methodology and findings	57
4.2.3 Hypotheses and methodology	57
4.2.4 Experimental approach.....	58
4.2.5 Results	62
4.3 Case study 3, interactive parent-child clothing.....	62
4.3.1 Purpose, methodology and findings	62
4.3.2 Background and research question.....	63

4.3.3 Prototype design following the CPCS model.....	64
4.4 Case summary	69
Chapter 5	
Emotional Evaluation, Data Analysis, and Discussion	71
5.1 Case study 2, Data analysis and evaluation on interactive couple clothing.....	71
5.1.1 Kansei evaluation I.....	71
5.1.2 Kansei evaluation II	73
5.1.3 Case discussion	76
5.1.4 Limitations and further research.....	77
5.1.5 Case conclusion.....	77
5.2 Case study 3, Data analysis and evaluation on interactive parent-child clothing	78
5.2.1 Selection of comparative evaluation objects	78
5.2.2 Selection of semantic opposite adjective.....	80
5.2.3 Participants' selection and evaluation methods.....	81
5.2.4 Differences between the two categories of parent-child clothing	83
5.2.5 Limitations and follow-up studies.....	85
5.2.6 Case conclusion.....	85
5.3 Summary.....	86
Chapter 6	
Knowledge Transfer and Enlightenment to Interactive Clothing Design	87
6.1 Knowledge Transfer.....	87
6.2 Completion of loops steps in the CPCS model.....	88
6.3 The “C” design principle for interactive clothing.....	91
6.4 The framework of the evaluation criteria for interactive clothing design.....	94
6.4.1 Background and significance	94
6.4.2 The structure of the evaluation criteria.....	95
Chapter 7	
Conclusion.....	99
7.1 Contribution	100
7.1.1 Main practical contribution of the study	100
7.1.2 Original contribution to knowledge science.....	101
7.2 Future research.....	103
Bibliography.....	105
Publications.....	117
Appendix	118

List of Figures

Figure 1. BioCouture project.....	2
Figure 2. Biohybrid wearable project.....	3
Figure 3. Smart clothing examples.....	3
Figure 4. The relationship between wearable devices, information technology, traditional clothing, smart clothing, and interactive clothing.....	5
Figure 5. Research ideas and methods	6
Figure 6. Number of patent application annual growth waterfall chart.....	7
Figure 7. Annual number of the patent application treemap	7
Figure 8. The trend in the number of research papers on smart clothing	8
Figure 9. Top 25 research areas of smart clothing literature treemap.....	14
Figure 10. Structure of the dissertation	21
Figure 11. Symbolic semantics model of clothing	24
Figure 12. Maslow's Hierarchy of Needs model.....	25
Figure 13. The synergy of clothing needs and Maslow's hierarchy of needs	28
Figure 14. Hierarchy and typology of clothing design.....	29
Figure 15. The synergy of Maslow's hierarchy of needs, clothing needs and clothing design.....	31
Figure 16. The interactive clothing evolutionary roadmap	31
Figure 17. The evolution of clothing function.....	33
Figure 18. The synergy of clothing function categories with psychology, sociology and market deeds	34
Figure 19. The DIKWS hierarchy	34
Figure 20. The consistency between the hierarchies of DIKWS and TFSI.....	35
Figure 21. The 5C architecture of CPS.....	36
Figure 22. The consistency between the hierarchies of DIKWS, 5C and the technical process of the interactive clothing	37
Figure 23. The interrelationships between properties of clothing and their evolutionary path.....	41
Figure 24. Evolutionary route based on psychology, sociology, and design (Humanities).....	43
Figure 25. Evolutionary route based on IoT and CPS applications (Technology)	43
Figure 26. Research roadmap	44
Figure 27. A CPCS architecture for interactive clothing in the hyper world.....	46
Figure 28. The logical relationships of each research method	50
Figure 29. The structure of trousers and electronic components.....	53

Figure 30. The prototype and patent certificate.....	54
Figure 31. The garment structure and electronic components.....	54
Figure 32. The prototype and patent certificate.....	56
Figure 33. Survey data for prototype selection.....	56
Figure 34. Clothing designs, labeled a-d	59
Figure 35. Pattern of style a-d	59
Figure 36. Electronic embedding design	61
Figure 37. Schematic circuit design	61
Figure 38. Photographs of prototypes visual effects	62
Figure 39. Pattern design and hardware embedding diagram.....	66
Figure 40. Circuit design	67
Figure 41. Photos of prototypes.....	67
Figure 42. Interactive effects of prototypes.....	68
Figure 43. Results of evaluation on emotional expression for non-interactive and interactive.	72
Figure 44. Evaluation object.....	73
Figure 45. Comparison of average values by designer, engineer and consumer clusters.....	74
Figure 46. The evaluation value of designer cluster to four kinds of smart clothing	74
Figure 47. The evaluation value of engineer cluster to four kinds of smart clothing	75
Figure 48. The evaluation value of consumer cluster to four kinds of smart clothing	75
Figure 49. Human-centered R&D process for interactive clothing.....	76
Figure 50. Photos of comparative categories.....	79
Figure 51. Evaluation value of 14 designers	82
Figure 52. Evaluation value of 23 engineers	82
Figure 53. Evaluation value of 36 parents	82
Figure 54. Knowledge transfer of this research.....	87
Figure 55. The symbolization of the signal	89
Figure 56. The process from signal to symbol	90
Figure 57. The cradle-to-cradle design process for smart clothing	91
Figure 58. The logical relationship of “C” principle for interactive clothing design	92
Figure 59. The structural relationship of evaluation criteria for interactive clothing design ..	97

List of Tables

Table 1. Classification of wearable devices research area.....	8
Table 2. Categories of organizations in 1998-2004	10
Table 3. Famous companies involved in the competition of smart clothing market	11
Table 4. Comparison of Maslow’s hierarchy of needs and Clothing needs	28
Table 5. Compare the development process of DIKWS with TFSI.....	35
Table 6. Comparison of the technical process of the 5C and interactive clothing.....	37
Table 7. Temperature test extraction record	55
Table 8. Pattern size.....	60
Table 9. Differences in the evaluation of average values	72
Table 10. Semantic opposite adjective pairs.....	80
Table 11. Example of an SD scale with seven points for adjective pair.....	81
Table 12. Results of the paired-samples T-test	83
Table 13. Top five value in prototype and traditional parent-child clothing	84
Table 14. The “C” principles and architecture of interactive clothing design.....	92
Table 15. AHP of the interactive clothing evaluation system.....	96

Chapter 1

Introduction

1.1 Background

Technology makes fashion more avant-garde, fashion makes science and technology sexier. The internet technology has continuously been integrated into social life, encompassing all aspects of clothing, food, living conditions, and profoundly changing our production methods and lifestyles.

Interpersonal communication is a kind of social relations, which is the main content of human life activities. Apart from using language as a tool, human interaction needs to be expressed by some non-linguistic tools, and clothing is one of the most critical non-linguistic tools. With the development of society, clothing plays a distinct role in human interactive activities.

As daily necessities of human life, clothing, especially fashion clothing lifestyle, carries the increasing physical and social properties. The development of clothing can also reflect the progress of science and technology, and often create a stunning topic such as wearable devices or smart clothing that has moved from the science fiction movie to the present market. This emerging field of smart clothing has brought a dramatic impact on academic research.

Since Thorp (1966) mentioned in his gambling counseling book “Beat Dealer” that he proposed the thought of a wearable computer idea in 1955 and completed the device design in 1961, and later Bass (1985) described shoe-based computers of the 1970s designed, wearable devices have developed rapidly. As early as a decade ago, researchers have begun to systematically explore the main development direction of smart clothing in the future (Ariyatun et al., 2005; Cho et al., 2009; Suh et al., 2010; Tao, 2001). In recent years, researchers have generally focused on high-tech approaches to implementing smart clothing design, with fruitful success in multifunction (Bahadir et al., 2013; Kan et al., 2015; Schüll, 2016; Perovich et al., 2014; Wright and Keith, 2014; Yu et al., 2014).

In recent years, the focus of cyber-physical systems (CPS) and the internet of things (IoT) have moved looks to the future of technology and how it can enhance human activity and experience. As a multi-dimensional smart mechanism with a deep interaction between physical and cyber world, the CPS/IoT will provide with the foundation of emerging and future smart services, and improve our quality of life in many areas (Duarte Filho et al., 2015; Huang et al., 2018; Barnaghi et al., 2015). Following the ascend anting application of CPS to the fashion industry, the academic and industry research concerns in this area across various disciplines stems have mainly been devoted to optimizing the interaction of smart clothing by the integration of information technology. The remarkable functions of carefully crafted are generating considerable interest (Barfield, 2015; Gilsoo, 2010), the development of smart clothing in daily life has aroused more attention, and adopted as the target direction of this research project.

1.1.1 Research subject

The research subject of this study refers to the interactive clothing, a topic on which there is little previous research, a category of smart clothing in the field of information science, which emphasizes the interaction between human and environment based on the integration of information science and traditional clothing, rather than the biological material science category of Bio-smart clothing.

At present, the research and development of smart clothing have two main ways:

On the one hand, the clothing materials are improved by means of chemical and physical methods from the “intelligent fiber” which refers to the changes in fiber length, shape, color, temperature, etc. due to the stimulated or change of external environments, such as color-changing fiber, shape memory fiber, tempering fiber, etc. (Tao, 2001, Lv, & Chen, 2016). The typical research projects include Suzanne Lee's “BioCouture” (2005) (Figure 1) that the clothing was “grown” from plant cells, and also “Biohybrid wearable” with breathing ability which designed by Yao, et al (2015) and Wang, et al (2017, a) (Figure 2);



Figure 1. BioCouture project (Top 50 Best innovations of 2010 in Time Magazine’s annual roundup)

Source: http://xsead.cmu.edu/uploads/media/path/365/biocouture_1.jpg;

<http://www.liveeco.co.za/2014/05/19/biocouture-growing-wardrobe-bacteria/>



Figure 2. Biohybrid wearable project

Source: <http://tangible.media.mit.edu/project/biologic/>

On the other hand, “smart clothing”, some of the more advanced examples can be seen in Figure 3, which embedded with electronic devices is the combination of electronic devices such as sensors, actuators, memory, data processors and communication components with clothing by means of embedding (Cho, 2009 a, b; Honarvar, & Latifi, 2016). Electronic products are the scientific and technological basis of clothing intellectualization, and at the same time, clothing has become the carrier of electronic products humanization. The integration of technology and fashion can be realized by embedding electronic devices into clothing, which not only does not affect the wearing effect, but also gives clothing information perception, computing, communication, control and other capabilities (McCann, & Bryson, 2009; Tao, 2005; Sazonov, & Neuman, 2014, Persson, et al., 2018). Interactive clothing is one of the second categories of smart clothing.

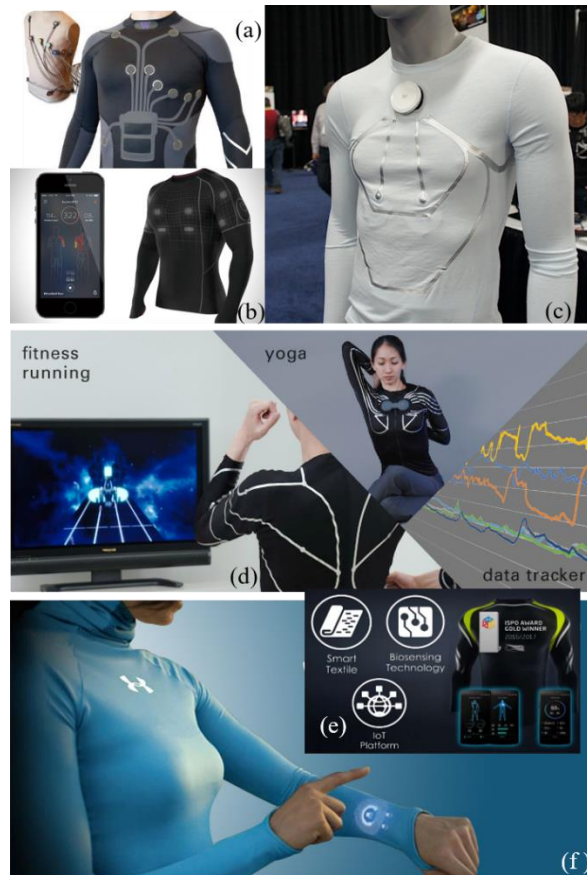


Figure 3. Smart clothing examples

Source:

- (a) Morrison, T., Silver, J., & Otis, B. (2014, June). *A single-chip encrypted wireless 12-lead ECG smart shirt for continuous health monitoring*. In *2014 Symposium on VLSI Circuits Digest of Technical Papers*, (pp. 1-2). IEEE.
- (b) <https://www.wearable-technologies.com/wp-content/uploads/2018/08/Top-5-smart-clothes-1.png>
- (c) <https://www.engadget.com/2018/01/07/xenoma-smart-clothing-dementia/>
- (d) <https://www.kickstarter.com/projects/961243492/e-skin-smart-apparel-hack-your-life>
- (e) <https://www.slideshare.net/AugmentedWorldExpo/stanley-yang-neurosky-biosignal-sensing-solutions-for-vr-ar-wearables-smart-clothing>
- (f) <https://blogs.systweak.com/2016/10/the-4-technologies-that-will-rule-the-fashion-industry-for-next-decades>

1.1.2 Definition of interactive clothing

Interactive clothing is an evolutionary branch of smart clothing, and also originates from the wearable devices or wearable computing (Figure 4). Gepperth (2012) separated the application scenarios of wearable computing into three categories: “Sensing and data analysis”, “Interfaces” and “Functionality and Aesthetics”. Ariyatun (2005), Van Langenhove & Hertleer (2003) and Zhang & Tao (2001) have summarized the type of interactivity of smart clothing and divided it into three categories: the first is only sense stimuli from the environment, it is one way communication; the second is can sense and react accordingly, it is two way communication; and the third is a complete interactive activity that it can sense, react and adapt themselves to the environmental conditions, it is interactive communication. At present, smart clothing has realized the first two communication functions under the concept of the IoT, and interactive clothing is precisely born in response to the third function of communication.

Although there is no clear academic definition of interactive clothing so far, interactive clothing should include the following characteristics:

- Interaction occurs as two or more clothing have a two-way effect upon one another. In the aspect of interactivity, it refers to the interaction between clothing and the body of the wearer, clothing interacts with the environment, and clothing interacts with other dressers. The interactive clothing can sense, react and adapt themselves to the environmental conditions, and it is interactive communication.
- Covering a wide range of interdisciplinary, including clothing design and engineering, information science, human-computer interaction, textile science, social psychology and industrial & art design. As Gepperth emphasized, aesthetics is an essential element.
- In essence, it is still clothing, and the interactivity is an additional feature. No matter how sophisticated and changeable the interaction is, it should not be divorced from the essential attributes and basic functions of clothing.

- In addition to the special information science function of Self-Monitoring Analysis and Reporting Technology (S.M.A.R.T., the term derives from the data security technologies commonly used in hard drives according to Wikipedia encyclopedia) that are owned by smart clothing and the basic physical functions of traditional clothing, the interactive clothing is more emphasizes that clothing can carry the media function of society and humanities in the process of interactive activities between people and their environment on the basis of information technology.
- Combining cyber-physical-systems (CPS) with clothing engineering design to input a certain physical signal into clothing, so the clothing can output a specific social symbol that people or clothing environment can perceive and generate corresponding interaction. This kind of social symbol is the expression form of the clothing as the interactive medium for people to interact with the environment.

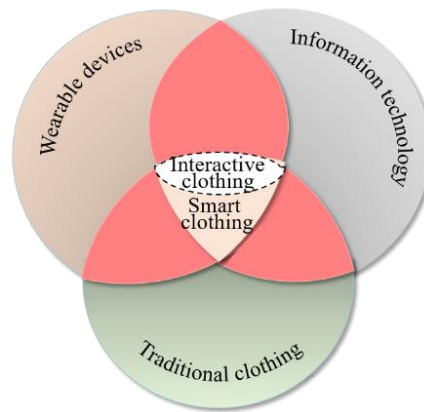


Figure 4. The relationship between wearable devices, information technology, traditional clothing, smart clothing, and interactive clothing

1.1.3 Research ideas and methods

This study was carried out according to the following logical sequence (Figure 5):

- In the research stage planning, it mainly includes the theoretical analysis stage, model building stage, practical application stage, model verification and summary stage.
- Regarding research contents planning, it contains mostly the derivation and building of the theoretical model, prototype development and emotional evaluation, model verification.
- Concerning research methodology planning, it mainly includes literature review, questionnaire, prototyping, Kansei engineering, semantic differential method and so on.

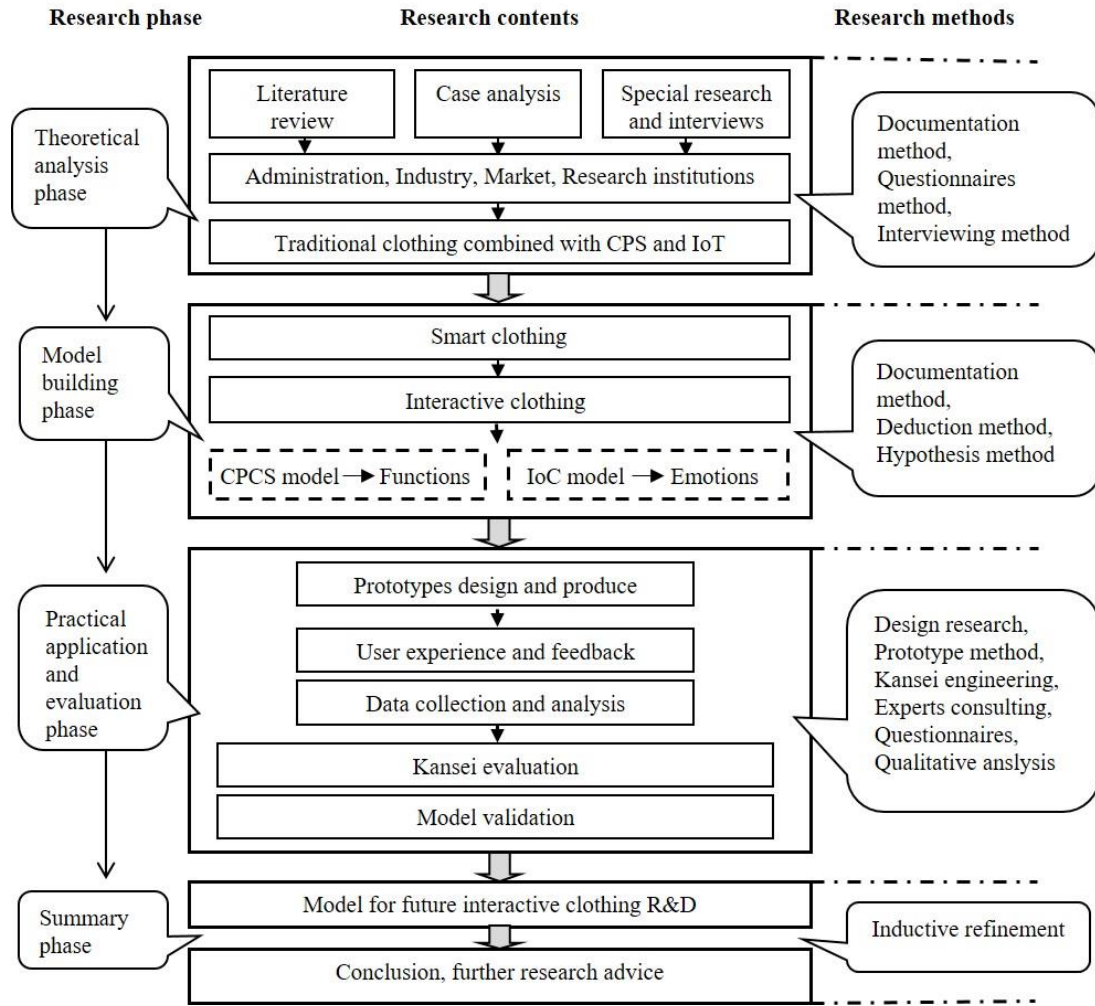


Figure 5. Research ideas and methods

1.1.4 Academic and industry research background

Because the interactive clothing originates from the smart clothing, the related research process analysis should base on the development process of smart clothing and wearable devices.

A literature review was carried out to investigate the R&D trend of the smart clothing and wearable devices. Wearable devices have a long history of development, ideas and prototypes have emerged in the 1960s, while devices with wearability appeared in the 1970s and 1980s. The wearable computer prototype developed by MIT Professor Steve Mann is one of the representatives. With the rapid development of computer standardized software and hardware as well as internet technology, wearable smart devices have become diversified, which has gradually shown significant research value and application potential in many fields such as industry, medical, military, education, entertainment and so on.

The methods and approaches of the literature review are as follows:

Firstly, the number of patent applications related to wearable devices is taken as the basis for analyzing the development process of smart clothing (Yan et al., 2016). The Derwent Innovation Index database was taken as patent retrieval platform, a retrieval strategy with the theme of “wearable devices” is constructed by technology decomposition. The results are de-noising, and the artificial interpretation determines the analytical data range. Figure 6 shows the annual trend in the number of patent application related to wearable devices from 1974 to 2018 May, and also can be seen that the three years with the highest number of the annual patent applications were 8016 records in 2014, followed by 5066 records in 2013 and 4898 records in 2015 (Fig. 7).

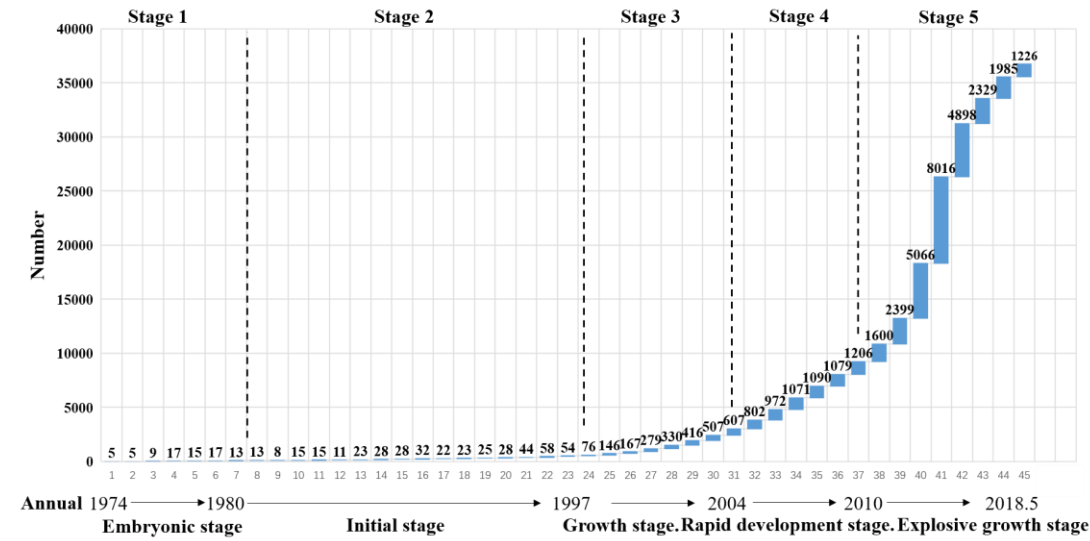


Figure 6. Number of patent application annual growth waterfall chart (from 1974 to 2018 May)

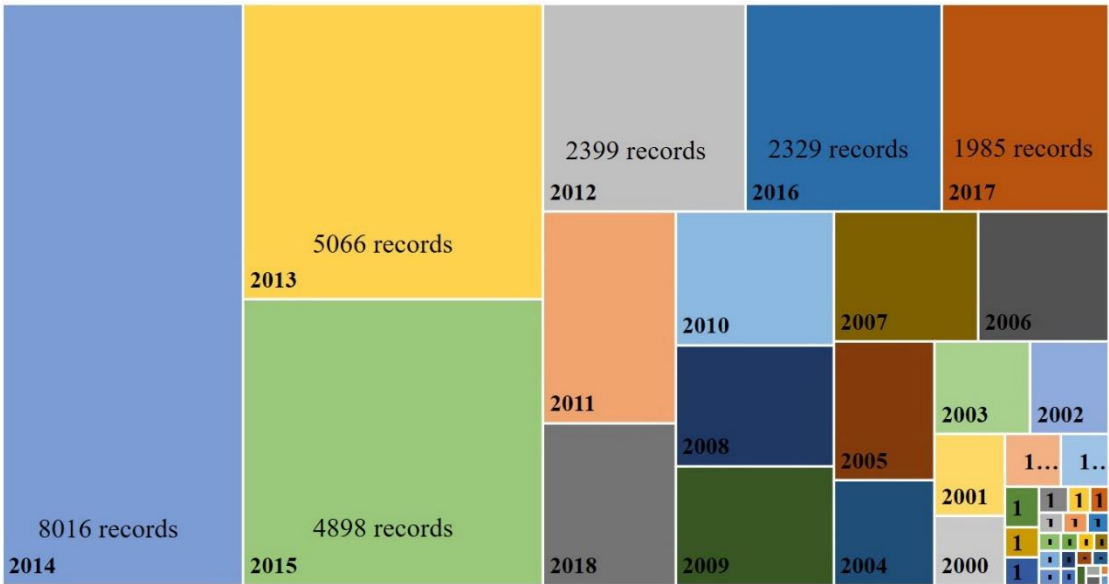


Figure 7. Annual number of the patent application treemap

Secondly, the number of research papers related to smart clothing is taken as another basis

for analyzing the development of smart clothing. The Web of Science was selected for the research papers retrieval platform, with All Databases as the target database, smart clothing as the keyword of the search topic, the deadline is October 2018. Figure 8 shows the trend in the number of research papers on smart clothing from 1983 to 2018, a total of 811 records. The source Databases include Web of Science Core Collection (595 records), MEDLINE® (252 records), KCI-Korean Journal Database (171 papers).

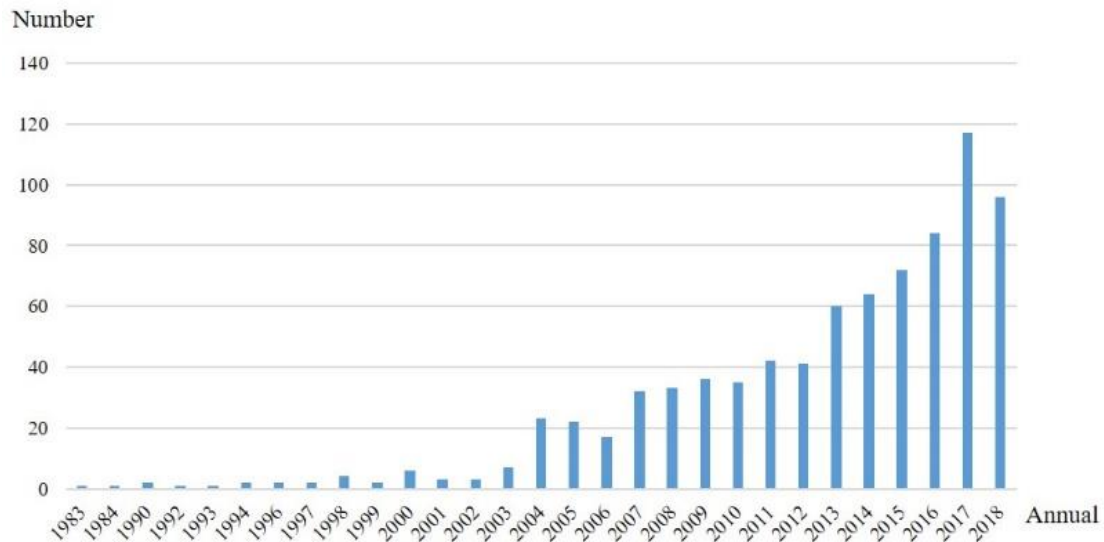


Figure 8. The trend in the number of research papers on smart clothing

Compared with the number of patents, research projects and academic journals (Amft, & Lukowicz, 2009; Ariyatun, & Holland, 2003; Ariyatun, et al., 2005), the results show that the patented technology in wearable devices mainly focuses on data input/output devices, diagnostic measurement, and human body identification, data processing, communication devices, wireless communications, optical systems, data security protection, program control, graphics recognition, sensors and other aspects (Table 1). The design evolution of smart clothing could be divided into five stages (Labeled in Figure 6) as follows:

Table 1. Classification of wearable devices research area

Research Area	Product Category
Fitness health	Sports monitors, fitness and heart rate monitors, smart sports glasses, smart clothing, sleep sensors, and mood measurer.
Healthcare	Cardiac and insomnia monitoring, stress detection, diabetic nephropathy treatment, wound infection Detection and treatment, surgical navigation, and functional rehabilitation training.
Industrial military	Driving safety monitoring, navigation, military exoskeleton, visual helmet night-vision goggles, and smart bulletproof vest.
Infotainment	Smart watches, smart glasses, augmented reality headphones, virtual reality helmet, and mind headband.

1) The embryonic stage (1960-1979)

Edward O. Thorp, a professor of mathematics at MIT, mentioned in his gambling counseling book, *Beat Dealer* (1966), that he first thought of a wearable computer idea in 1955 to increase the winning percentage of roulette. And in 1960-1961, he was in cooperation with another developer to complete the development of the device (Thorpe, 1998), which could represent the original prototype of wearable devices.

By the 1970s, some institutions in the United States and Japan had begun to apply for relevant patents in the field of wearable technology. The number of patents in the initial stage was minimal, with an annual average of fewer than 50 patents. In 1977, C. C. Colins, from Smith Kettlewell Eye Research Institute, designed a vest for the blind or visually impaired, whose head-mounted camera was converted into tactile imagery through the mesh on the vest, allowing the blind to “see” (Swanson, 2014).

2) The initial stage (1980-1997)

During this period, design methods were considered technology-driven (Orth, 1998) because most research and development focused on wearable devices and the application of advanced technologies. For example, Steve Mann (1996, 1997) embedded controllable camera equipment in a specially designed backpack with a head-mounted camera. Randell (2001) predicts that the integration of sensing and display technologies will create many opportunities for textile manufacturers. So the researchers and their team developed Cyber Jacket, which integrates position sensors (GPS), displays, and so on, to prove this possibility. However, this prediction is based on the trend toward miniaturization of electronic devices, not consumer demand. Whether or not people carry electronic devices, which means they want them to be part of their clothes and operate unnoticed without user awareness, is controversial. Besides, clothing design and business input have been neglected. As a result, products are more “portable” than “wearable”; for example, the MIT wearable computer (O’Mahony, 2002).

3) The growth stage (1998-2004)

From the end of the 20 century to the beginning of the 21st century, the internet is booming. During this period, the microprocessor and sensors and other electronic components of the production of small volume, low power consumption, high precision continuous development. And with the constant improvement of the computer function, the quality of image processing is getting higher. These technologies have led to the development of wearable devices, the number of patent applications in this field has begun to increase significantly and grew faster.

The awareness and participation of the fashion and textile industry increased significantly in this stage-four types of organizations involved in smart clothing development as shown in table 2.

Table 2. Categories of organizations in 1998-2004

No.	Categories	Organizations
1	Academic institutes	MIT Media Lab, Royal College of Art, University of Bristol, Central Saint Martins College of Art & Design
2	Governmental organization	NASA in the USA and Ministry of Defence in the UK
3	High-tech companies	Nokia, Philips, Ericsson, Motorola,
4	Clothing companies	Levi's, Polo

As a result, the number of collaborative projects in the electronics and fashion sectors has increased rapidly, such as the Cyberia project (Rantanen et al., 2000). Also, textile and clothing experts began to create their R&D (Clarke and O'Mahony, 1998). Senior fashion designer Alexandra Fede, for example, has worked with DuPont to develop new smart clothing by advanced technology. Although applications have become more wear-resistant, most of the results are still prototype clothing because of technological underdevelopment, such as Philips and Levi's ICD+ jackets (Meoli and May-Plumlee, 2002) and SCOTT eVast (Forman, 2001) although they have offered in limited numbers and focus on the niche market. In addition, product concepts, such as embedding fiber-optic screens on clothes (Gould, 2003), still do not satisfy the requirements of the mass market.

The number of smart clothes available on the market increased. Notable examples are the Met 5TM jacket (Ward, 2001), Adidas Smart Shoes and GapKid sweaters with embedded FM radios. Most development teams (Rantanen, 2000) have adopted a wide range of multidisciplinary approaches and user-centric design. In addition, the boundaries of applications extend to new areas.

It also can be seen from Table 2 that the electronics sector is more actively involved in project development than fashion because most projects were led by the electronics R&D team during this period.

4) The rapid development stage (2005-2010)

During this period, smart clothing was no longer embedded simply electronic components but emphasizes the development of smart textile materials. As a result, the number of wearable devices gradually increases, its wearability has been significantly improved.

Professor Takagi (1990) first proposed the concept of intelligent materials based on the idea of integrating information science into the configuration and function of materials. Later, American scholars call it smart material (Gu, & Chen, 2006). Professor Shi Changxu, editor-in-chief of the Material Dictionary, explains the smart material as a material that mimics the life system with both sensory and driving dual functions. That is, the smart material cannot only perceive the change of external environment or internal state, but also can change one or more properties of the material in real time, and make the desired

response, also known as smart material, through some feedback mechanism of material itself or outside (Schwartz, 2002). Perception, feedback, and response are the three main elements of smart materials. One notable feature of smart materials is the combination of high-tech sensors and actuators with traditional materials, giving the material new properties that make inorganic materials more and more biologically specific properties. Compared to the smart fiber, smart clothing is more accessible to achieve “smart” by integrating sensing elements, feedback elements, and response elements.

The concept of “interactive smart textiles” put forward by Professor Tao (2006) is of great practical significance and guidance for smart clothing development. She proposed that the interactive smart textiles refer to textiles that can perceive and respond to stimuli or environmental conditions dominated by electricity and light in an artificial or predetermined manner. She also contributed to wearable electronics and photonics (2005) which covers topics related to materials and devices, structures and system architectures, and various issues that fashion designers need to face.

5) The explosive growth stage (2011 to present)

Table 3. Famous companies involved in the competition of smart clothing market

Company	Location	Domain
AIQ Smart Clothing Inc.	Taiwan, CHINA	Sports & fitness, home & leisure, outdoor & leisure, home care & health care
Clothing Plus Ltd.	Finland; USA	Fitness and Healthcare
Textronics, Inc. (Adidas)	USA	Sports & fitness, health & wellness, military & safety
Sensium Healthcare	UK	Healthcare
VivoMetrics	USA	Wearable technology
Schoeller Technologies AG	North America, Europe; Asia	Functional clothing and textiles
Grado Zero Espace	Italy, Europe	Wearable Technology
Athos	California, USA	Fitness & Healthcare
Catapult Sports	Australia	Wearable Technology
Heddoko	Montréal, Canada	Ergonomics and Sports
Hexoskin	Montréal, Canada	Fitness & Healthcare
OMsignal	Montréal, Canada	Wearable Technology
Sensoria Inc.	USA	Fitness & Healthcare
Ralph Lauren Corporation	USA	Sports & Fitness
LikeaGlove	Israel	Wearable Technology

Source: Hanuska, et al. (2016). *Smart clothing market analysis*. University of California Berkeley.

Since 2011, wearable technology patent applications have shown a rapid development trend, more and more fashion companies and institutions have begun to involve in this field, and continue to develop new wearable products, the number of patent applications

has become an explosive growth trend. This phase is characterized by institutions taking market share first through new products and then planning their patent layout in various ways (Wei, 2014). Internet companies continue to expand their scope of technology protection through the method of patent acquisition. With the accumulation of technology for many years, mobile terminal enterprises continue to set up new barriers to technology protection. However, with the increasing improvement of the cyber-physical system (CPS) and the internet of things (IoT) technology in the information technology industry, wearable does not only meets people's entertainment and leisure needs but also develops towards health monitoring, convenient medical care, and intelligent manufacturing.

Contrary to the growth stage (1998-2004), since 2011, the enthusiasm of fashion industry to participate in smart apparel is significantly higher than the information electronics industry, and smart clothing has begun to shift from the past focus on the function to real daily life clothing transformation. Although the smart clothing industry is still in its infancy, it is characterized by fierce competition and a large number of new entrants. Some of the most recognized companies in the smart clothing market are shown in Table 3.

According to the ABI Research's Wearable Data Analytics and Business Models report released in Dec. 2017: "Wearable data and analytics services revenue will reach over US\$838 million in 2022, increasing from over US\$247 million in 2017, a CAGR of over 27%; The smart clothing market will get a 45% CAGR." In recent years, researchers have generally focused on CPS/IoT approaches to implementing smart clothing design, with fruitful success in sports, health care and other fields (Bahadir et al., 2013; Kan et al., 2015; Perovich et al., 2014), and a small amount of sportswear has been put into the market. As the 2016 and 2017 Milan, Paris, New York, and Tokyo Fashion Week shows, especially the Fashion Tech Festival 2017 in Paris, 2018 in Berlin and also 2019 will be in Berlin, which is bringing together fashion designers, engineers, and major IT companies invested in developing the future of design for smart clothing and accessories, more and more fashion brands' product development and the effectiveness of the fashion show have adopted CPS/IoT approaches.

Nevertheless, some products are just accessories of clothing rather than the clothing itself. Some intelligent effects are limited to specific places. Undeniably, technological innovation can enhance the fashion brand's marketing campaign and catch consumers' great attention, CPS in future will be integrated into our daily clothing life (Wright and Keith, 2014; Schüll, 2016).

1.2 Existing problems and research motivations

Despite its impressive track record in smart clothing research and development, we still have to confront with several existing research problems or development bottlenecks from

correlative humanities science and information technology respectively. These existing problems and challenges are the motivation of this research to choose interactive clothing project as the research topic.

- 1) In the perspective of social psychology and human-centric design principle, the smart clothing R&D approach is not driving on the right path.

According to the perspective of social psychology, human beings are the people who are living in the human society, the interpersonal communication, as well as individual symbolic interaction, are the foundation for individuals to form the activities of society (Blunter, 1994). Clothes that people wear should be an auxiliary sign or code means for people to interact in society (Leeds-Hurwitz, 2012). Therefore, according to the human-centric product development principles (Buchanan, 2001; Norman, 2005; Steen, 2012), smart clothing should be extended to the direction of assisting interpersonal communication in the social activities. This assisting interpersonal communication is precisely the value and significance of interactive clothing research.

Blunter (1994) has proposed that human society as a symbolic interaction. He defined “symbolic interaction” to the distinctive character of communication as it takes place between human beings.

“The peculiarity consists in the fact that human beings interpret or define each other’s actions instead of merely reacting to each other’s actions. Their response is not made directly to the actions of one another but instead is based on the meaning which they attach to such actions. Thus, human interaction is mediated by the use of symbols, by interpretation, or by ascertaining the meaning of one another’s actions...” (Blunter, 1994, pp. 263)

“Human society is made up of individuals who have selves; that individual action is a construction, being built up by the individual through noting and interpreting features of the situations in which he acts; that group or collective action consists of the aligning of individual actions, brought about by the individuals interpreting or taking into account each other’s actions....” (Blunter, 1994, pp. 266)

- 2) From the perspective of clothing design, smart clothing lacks aesthetic purposes or the humanistic attributes of fashion.

The imbalanced contribution from electronics and fashion industries is undeniable (Wang et al., 2018). According to the research papers retrieval and results analysis on the Web of Science, as of October 2018, the top 25 research fields of 812 research papers related to smart clothing (Fig. 9), excluding the field of humanities and art design. It is a shocking result. It can be concluded that long-term research on smart clothing has only experienced

technological development without artistic design rendering.

The development of smart clothing is not yet known as the clothing design in the field of humanities and art, and it is not fashionable enough to enter our daily wardrobe. According to the five stages in the development of wearable devices mentioned above, it is not fashion designers who are leading this emerging area but IT and electronic technologists (Stead et al., 2004).

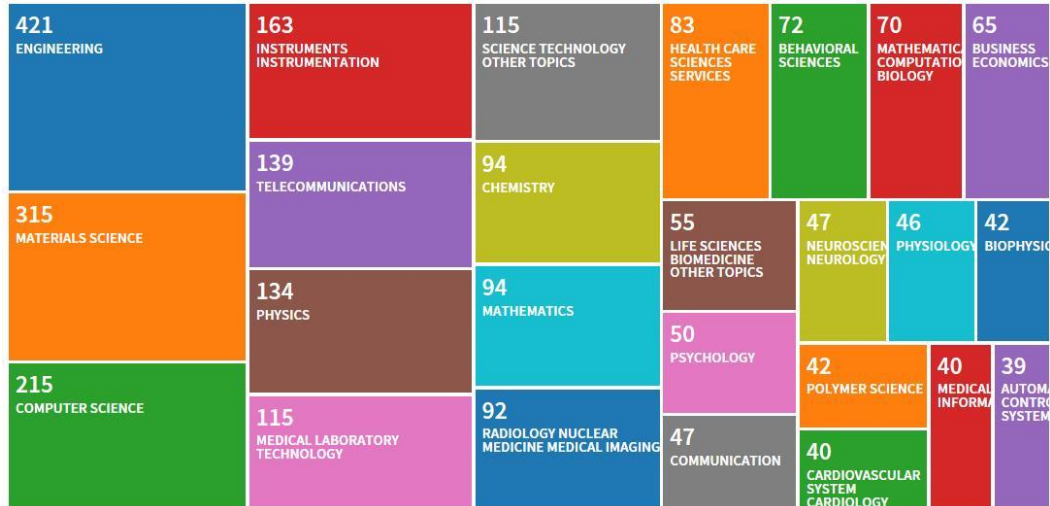


Figure 9. Top 25 research areas of smart clothing literature treemap

- 3) From the perspective of the material and social attributes of clothing, some smart clothing has become the dominant of the wearer rather than the wearer's appendage.

Because of many innovations in this field are driven by technological developments, rather than users' needs and preferences (Steen, 2012). The result of putting the cart before the horse leads to the smart clothing not serving people, but people serving the clothing. Clothing should be an appendage of human beings, and should not make people an accessory to clothing.

- 4) The contradiction between clothing as a high-tech carrier and clothing as an interactive symbol of human emotion carrier.

Researchers have generally focused on high-tech approaches to implementing smart clothing design with multifunction. Nevertheless, the complex sociological aspects of clothing, i.e., its interactive symbolism and properties of emotional expression, should not be ignored. A long time ago, Naisbitt & Cracknell (1982) had proposed that we are moving toward High Tech and High Touch in two directions and humans are trying to give each new technology a compensatory response. This reaction is a kind of non-material emotional value, humanistic connotation pursuit, and the balance of design and emotional factors. Clothing has both material attributes, and complex social attributes (Barnard, 2002; Owyong, 2009; Weizhen et al., 2017), the expression function of emotion is an important design element which cannot be neglected in the development of smart clothing.

- 5) In the perspective of information technology, the architecture model of smart clothing development is not perfect.

When we extend the functional definition of interactive clothing to provide interaction between different wearers or groups rather than just personal interaction with data, it is a significant challenge to apply cyber-physical systems (CPS) in the development of interactive clothing. That is, how to meet the differentiated needs of different wearers and the differences in various attributes among each wear groups. Also, most of the existing CPS architecture research is based on the logic framework of information science, but not the specific technical guidance for the non-information engineering personnel. Therefore, it is critical to optimize the CPS technical architecture which should comply with wide applicability for interactive clothing (Chen et al., 2016; Alhafidh et al., 2017; Longo et al., 2017).

- 6) From the perspective of network communication under the IoT architecture to assess, the communication of current smart clothing is not perfect enough.

Rafaeli, Sudweeks & McLaughlin (1998) proposed that the net communication is divided into three levels: one-way communication, two-way communication, and interactive communication. Ariyatun (2005), Van Langenhove & Hertleer (2003) and Zhang & Tao (2001) have summarized the type of interactivity of smart clothing and divided it into three categories: the first is only sense stimuli from the environment; the second is can sense and react accordingly; and the third is a fully interactive activity that it can detect, react and adapt themselves to the environmental conditions. The current smart clothing only implements the first two functions, and the third function requires a new type of clothing to undertake this historic mission.

- 7) Failure to systematically interpret the principles and processes of interaction.

Current researchers seldom dabble in the systematic research of smart clothing from information modelling to humanistic evaluation, most of them analyzed the information technology application or humanistic design from the single academic background (Trindade et al., 2016; Kim et al., 2016b; Salim et al., 2014; Weizhen et al., 2017), which may leads their inability to systematically explain the principle and process of how to extract data, transform and form humanistic feeling of the interactive clothing.

- 8) The current category of smart clothing is not rich enough to fit into daily life, limited to the stage effect of the fashion show.

Most smart clothing development is applied to particular functions or special situations rather than to the needs of everyday life. It has been suggested in the previous study (Wang et al. 2018) that some fashion brands have adopted VR and other technologies in the fashion show to rendering the atmosphere, contributes to forming the interaction between models and the audience. However, the visual effects of these clothing will disappear if

leave the show scene. Obviously, this design has not yet entered the daily clothing life category.

As Prof. Hiroshi Ishii from MIT proposed in the 2016 Symposium on System Integration, the technology soon becomes obsolete, but the true research visions can last longer. For smart clothing or interactive clothing research, art & philosophy, design & technology, art & aesthetics should all be coordinated development. The choice of interactive clothing as a research topic is to deal with the current situation and challenges of the seven deficiencies mention above, and strive to develop a new approach for the research of interactive clothing from the perspective of academic theory and practice.

1.3 Research aims and objectives

The overall purpose of this research is to bridge the gap between Cyber-Physical Systems (CPS) in the field of information science and emotional evaluation in the field of humanistic science, to minimize the unbalance between human emotions and wearable smart technologies for interactive clothing innovation, to investigate how the transformation could be realized from information to knowledge in the process of interactive clothing design. By optimizing the CPS architecture model of interactive clothing design and conducting the Kansei Engineering (Nagamachi, 2011a, b) analysis of wearers' evaluation, to explore the R&D elements based on the CPS or the internet of things (IoT) technology, and suggest practical implication for interactive clothing design.

Specific research objectives were as follows:

This research will verify the concept of smart clothing development that “technology makes fashion more avant-garde, fashion makes science and technology sexier.” And to break the undesirable situation that the current research of smart clothing concentrates on health care or sport monitoring fields, but ignores the demand of the social interpersonal communication in the wearer's daily life.

- To define the concept of interactive clothing, building an R&D theoretical model for interactive clothing.
- To build an innovative Cyber-Physical-Clothing Systems model, and analyses its feasibility with the interactive clothing prototyping development as a case.
- To explore the development direction of smart clothing in the future and to analyze the possibility of realizing the internet of clothes (IoC) based on CPS/IoT technology.
- To investigate the transforming from the input of the physical signal to the output of the social symbol in the prototype development process.
- To establish a basic framework of interactive clothing design evaluation criteria, to encourage the object of evaluation to develop in the right direction and objectives.
- To reveal the design and development principles of interactive clothing from the

perspective of humanities and technology, and guide the development of interactive clothing.

1.4 Research question

To attain the objectives mentioned above, this research will answer one Major Research Question (MRQ) and three Subsidiary Research Questions (SRQ).

1.4.1 Major research question

What happened the social semantics of the interactive clothing transform from the information stage to the knowledge stage in the architecture of CPS?

This question includes three levels of content:

- According to the research dimensions of clothing social psychology and semiotics, as a social product, clothing has special functions of social symbols and information transmission (Steffen, 2009a). Since the dimensions of communication and characterization are more evident in clothing than those of most other commodities, this field has been attracted to research topics from the perspective of anthropology (Sahlins, 1976), psychology (Sommer, & Wind, 1986), sociology (König, 1971) and semiotics (Barthes, 1983). The research of interactive clothing is also inseparable from these fields.
- Although interactive clothing is advertised as a scientific and technological product, it is still clothing, in essence. Therefore the research of interactive clothing also needs to explore its smart semantics (Steffen et al., 2009b) such as information transmission function.
- The smart semantic transformation of interactive clothing is also the realization process of data-information-knowledge-wisdom (Krippendorff, 2006). How to apply the CPS principle of information science to realize the change from physical information into a kind of consensus semantics of human society is an interdisciplinary research question.

1.4.2 Subsidiary research questions

Three Subsidiary Research Questions (SRQ), according to soft system methodology, i.e., the “WHY,” “HOW” and “WHAT” as follow.

SRQ1: Exploration of research and development approaches.

Why does the R&D of interactive clothing worn in daily life need to integrate smart technology with emotional design and humanistic evaluation simultaneously?

SRQ2: Investigation of technical means.

How the technology transformation is could be realized between the signals in the field

of information physics and the symbols in the various dimensions of humanity and society?

SRQ3: Refinement of design principles.

What does the design principles of interactive clothing should be valued in the context of CPS's growing prosperity?

1.5 Significance of the study

This research topic belongs to interdisciplinary research, a topic on which there is little previous research. The subject takes interactive clothing as the research carrier, integrates data extraction and signal input in the field of information science, with humanistic emotional evaluation and the output of social symbols in the field of knowledge science, and conducts theoretical and practical research from the perspective of application in the CPS/IoT era.

1.5.1 Theoretical and academic level

1) Conceptual innovation

This research innovatively and clearly puts forward the concept of interactive clothing, a topic on which there is little previous research, will also explore the new development path of smart clothing.

2) The significance to knowledge science.

This research will integrate the humanistic and technical perspective, put forward the technical development process, design principles and evaluation criteria framework of interactive clothing, and initially establish the knowledge framework of interactive clothing design and evaluation.

The level and function of the interaction between human beings and the environment, human interaction, object and object interaction in knowledge science will be identified and classified. Taking the prototype development process of interactive clothing as case, the DIKW model from data to information, from information to knowledge, from knowledge to wisdom will be systematically completed. From the perspective of knowledge management, this research will dismantle and analyses the transforming from the input of the physical signal to the output of the social symbol in the prototype development process of interactive clothing.

1.5.2 Industrial level

This topic expands the industry chain of the clothing industry, not only integrating the main elements of the traditional clothing industry but also adding CPS/IoT technology, which makes

clothing and clothing, clothing and environment, clothing and people interact. More importantly, it puts forward the concept of the internet of clothes (IoC), that is, the industrial prospect of interaction between people in social groups through clothing.

1.5.3 Application level

This topic focuses on the social needs of the next 10-20 years, especially the interactive clothing needs of the ageing society is of great significance. With the continuous development of the information society, Smart Home, Smart City, and intelligent transportation will bring more convenience to our lives. At the same time, in the face of the elderly's living needs, emotional needs and communication needs, the interactive clothing will become a vital carrier medium in the future.

Also, this topic introduces the CPS technology into the design of interactive clothing in the art & humanities field and puts forward the technical architecture of interactive clothing development, that is, an innovative CPCS model, from the perspective of expanding the application field of information technology.

1.5.4 Product design and development method level

In response to the problem of “cold” and lack of emotional semantics in science and technology, this research will integrate human-centered design principle, emotional design methods, and Kansei engineering evaluation approach into the field of interactive clothing project development. And advocating the essential attribute of interactive clothing design still belongs to the category of humanities and arts, even if scientific and technological functions accompany this kind of clothing.

1.6 Structure of the dissertation

The structure of the dissertation is shown in Figure 10.

Chapter 1, Research Background.

(1) Establishing and defining the research subject of interactive clothing; (2) Analyzing the academic and industrial background, existing problems and challenges; (3) Putting forward the purpose and motivation of the research; 4). Explaining the questions and significance of the research.

Chapter 2, Literature Analysis and Model Derivation.

(1) Analyze the relationship between interactive clothing in psychology, sociology, and industrial design from the perspective of humanities; (2) Analyze the application form of interactive clothing in the field of IoT/CPS technology from the standpoint of technology; (3)

Deduce the trend of clothing evolution and put forward the concept of IoC.

Chapter 3, Research Model.

(1) The CPCS model was created. Integrate IoT data advanced theory and CPS architecture to create a technical process model for interactive clothing development; (2) The research ideas of prototype development, evaluation, model verification, and model re-construction are put forward.

Chapter 4, Prototyping.

Prototype 1 infant smart clothing is used to validate the application of IoT technology; Prototype 2 interactive couple clothing is used to verify the implementation of CPS technology; Prototype 3 interactive parent-child clothing is developed following the technical process of the CPCS model.

Chapter 5, Prototype Evaluation.

(1) Kansei engineering evaluation and data analysis; (2) Explore the advantages and disadvantages of prototypes, summarize evaluation models, and refine interactive clothing design elements.

Chapter 6, Result models.

(1) Signal and symbol conversion progress model of interactive clothing; (2) Design principle model of Interactive clothing; (3) Architecture model of the interactive clothing design evaluation criteria.

Chapter 7, Conclusion

Summarize the theoretical innovation and contribution.

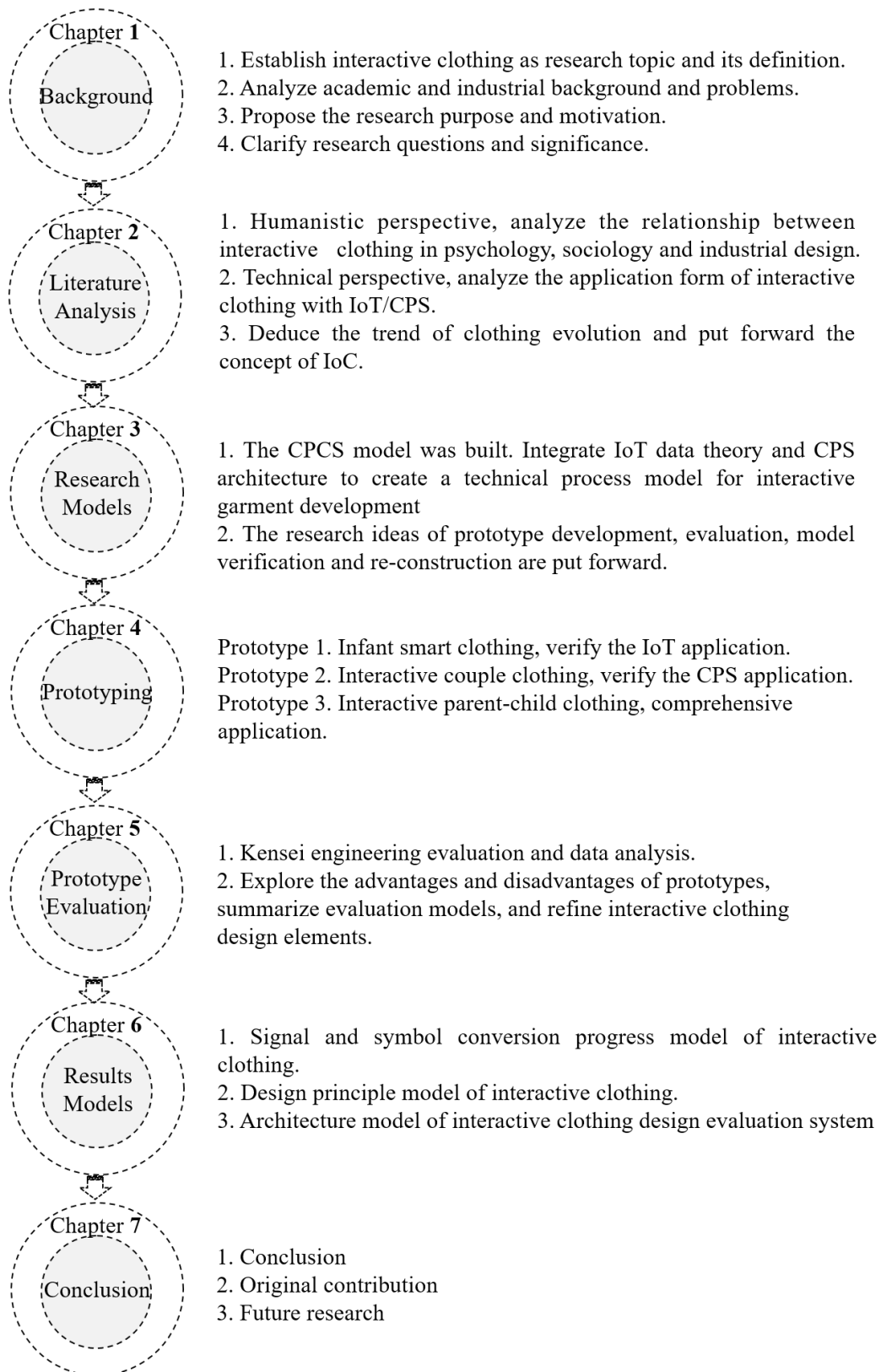


Figure 10. Structure of the dissertation

Chapter 2

Literature Review, Definition and Deduction

The research of product development or the deduction of its future development cannot be separated from the product's past and current essential attribute and its development law. From the material level to the spiritual level of technical and humanistic perspectives, the related research literatures are classified for building a pyramid deduction analysis model.

2.1 The social psychology and semiotics of clothing

2.1.1 Symbolic semantics of clothing

The study of the symbolic semantics of clothing is helpful to analyze the essential attributes of clothing. As far back as the 17th century, English philosopher Locke (1690) used the word “semiotica” in the last paragraph of his book “An Essay Concerning Human Understanding,” which means “the theory of symbols.” In the middle of the 20th century, great strides were made in the research of clothing symbols.

Although research book on clothing and its functions had emerged in the 19th century, interdisciplinary research book on the psychological or social functions of clothing appeared on the first half of the 20th century—for example, *The Psychology of Clothes* (1930).

The Fashion System (Barthes, 1983) is a sociological classic. Its most significant contribution lies in illustrating the symbolism of fashion, explaining that fashion is used by the media as a communication tool to elevate clothing from the material level to the spiritual level. Barthes divided clothing into three categories. The first category is the material level of clothing, which is well understood. The second category is “represented clothing”. If the material level of clothing is its original appearance, is represented by the pictures, language re-translation, processed clothing, is not the same as the original clothing, and the spiritual value of clothing is also added in the process. The third category is used clothing, that is, clothing worn by consumers after purchase. This is given a different meaning, such as personal information and emotion.

Clothing is the product of human civilization and an essential part of human culture. Almost

from its origins, clothing combines the practicality of protecting the body, maintaining life, and satisfying the role of self-expression. The former is the material attribute of clothing; the latter is the social attribute of clothing (Wang et al., 2018b). With the progress of society, clothing constantly adds new social attributes. Clothing cannot only satisfy the desire of self-expression, but different styles and materials of clothing in a specific social system can also represent different identities, status, can reflect the different ideas, attitudes, concepts and so on (Morgado, 1993). In this case, clothing is “something that can represent something” which is a symbol. Therefore, we call clothing is the symbol is not based on the point of view of material attributes, in fact, the social attribute of clothing is the necessary condition for clothing to become a symbol.

Undoubtedly, clothing symbol belongs to a kind of cultural symbol. It has many common characteristics with an architectural symbol, film symbol, theatrical symbol and so on. In addition, clothing can be used to cover the body, but also convey meaning. Semiotologist Roland Barthes (1964) called clothing a functional symbol which originated from practicality.

Langer, Susanne K. (1953, 1957) divided symbols into inference symbols (i.e., linguistic symbols) and representation symbols (i.e., non-linguistic symbols). The former is used for scientific analysis and exchange of ideas, while the latter is used for artistic insight and expression of emotion. Artistic symbols belong to the representation symbols.

On the one hand, clothing, as a necessity of life, plays a role in protecting the body and maintaining life. It must conform to ergonomic principles and meet the requirements of human comfort. In this respect, clothing symbols have the basic characteristics of inference symbols. But at the same time, clothing, as a product of human social life, is a symbol of the human tendency towards “natural humanization” in the development of human culture. It embodies different social images of human beings in different societies with various forms. From this point of view, clothing symbols have the same characteristics as poetry, music and painting and other artistic symbols. Therefore, we cannot merely judge whether the clothing symbol belongs to the inference symbol or the representation symbol.

2.1.2 The inference and representation symbols of clothing

Summarizing the social semiotics and archaeological research results associated with clothing, it can be concluded that clothing has multiple attributes (Wang et al., 2018b). The interrelationships between attributes of clothing and their evolutionary path mainly include five (also can be said to be six) attributes or symbols ranging from low-level to high-level as follows (Figure 11).

The inference symbols include:

- 1) Improving warmth and comfort (Pedersen, 1923; Toups et al., 2010);
- 2) Providing modesty and protection (Dunlap, 1928; Kittler et al., 2003).

The representation symbols include:

- 3) Displaying logos (Harms, 1938; Gilligan, 2010), and also reflecting a certain level of technological development (Twigg, 2009; Park et al., 2014);
- 4) Conveying certain social and cultural connotations (Harms, 1938; Feinberg et al., 1992; Lennon & Davis, 1989a, b; Roach & Eichler, 1979; Owyong, 2009); and
- 5) Facilitating communication and expression (Bohn, 2004; Norman, 2004; Kaiser, 1983; Hsu and Burns, 2002; Barnard, 2002; Leeds-Hurwitz, 2012).

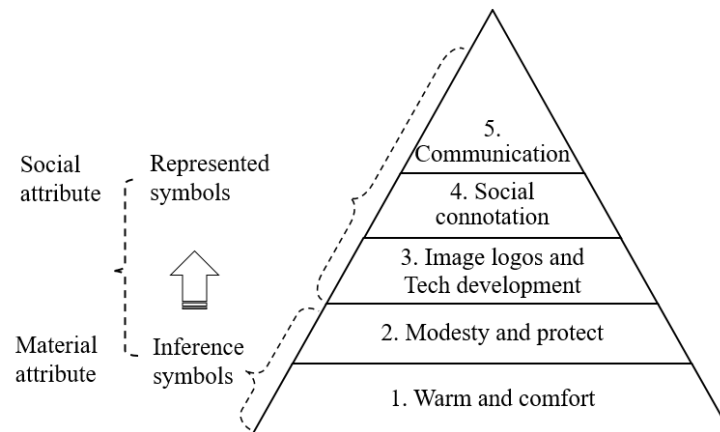


Figure 11. Symbolic semantics model of clothing

Through the symbol of clothing, people show the characteristics of their individual or group and realize the identification and connection in communication and interactive activities. Through the interpretation of clothing symbols, people have established a kind of interpersonal communication rules. Because of the rich meaning carried by symbols, it has a significant influence on human communication.

Therefore, it is of great significance to interpret human clothing behavior from the perspective of semiotics and to explore the effect of clothing symbols on interpersonal communication activities or interpersonal relationship. The study of interactive clothing is also inseparable from the interpretation of the semantics of clothing symbols.

2.2 The relationship between clothing needs and Maslow's hierarchy of needs

2.2.1 Maslow's hierarchy of needs

Maslow's Hierarchy of Needs (Maslow, 1943; 1968) is a valuable assessment tool that is used in the research fields of clothing demand trend.

As can be seen from Figure 12, the five-level hierarchy model can be divided into basic (or deficiency) needs (e.g., physiological, safety, love, and esteem) and growth needs (self-

actualization) (McLeod, 2007; Poston, 2009).

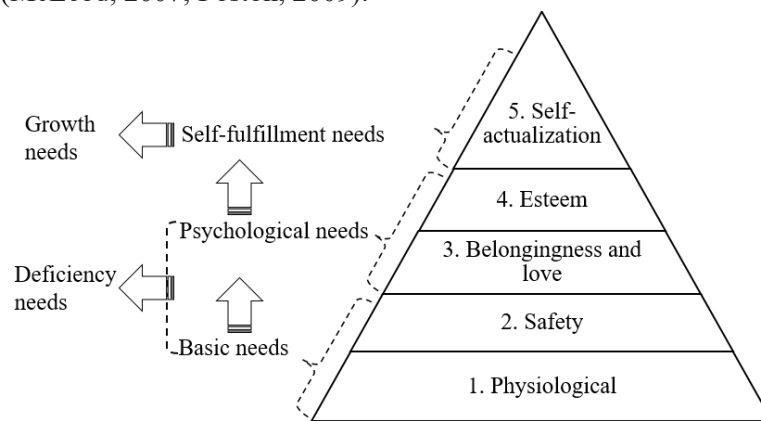


Figure 12. Maslow's Hierarchy of Needs model (Maslow, 1943; McLeod, 2007; Poston, 2009)

Such deficit or basic needs can be stimulated when people are not satisfied. Moreover, the need to meet these needs will become stronger with the prolongation of the time denied. Individual's needs must satisfy the lower basic requirements before they progress to the higher level of growth needs. Once these needs are reasonably met, individuals are no longer motivated by them, the highest complex level of self-actualization can be achieved (Tay, & Diener, 2011). The original hierarchy of needs five-level model includes:

1) Biological and Physiological needs

That is the most basic requirement for human survival, such as food, clothing, shelter, and clothing. If these needs are not satisfied, human survival will become a problem. In this sense, physiological needs are the most powerful driving force for people to act.

2) Safety needs

This is the need for human beings to safeguard their safety. Of course, once this demand is relatively satisfied, it will no longer be an incentive factor. The keywords include security, order, law, stability, health and wellness, safety against accidents and injury, freedom from fear.

3) Love and belongingness needs

People have a feeling of belonging to a group, hoping to become a member of the group, and care for each other. The keywords include friendship, intimacy, affection, and love, from workgroup, family, friends, churches and religious organizations, and romantic relationships.

4) Esteem needs

Everyone wants to have a stable social status and demands that the abilities and achievements of the individual be recognized by society. Maslow believes that respect for the need to be satisfied, can make people full of confidence in themselves, enthusiasm for society, and experience their value. The keywords include achievement, mastery, independence, status, dominance, prestige, self-respect, and respect from others.

5) Self-Actualization needs

This is the highest level of needs, that is, the peak of the pyramid. It refers to the need to achieve personal ideals, aspirations, to maximize the ability of the individual, to complete all things commensurate with their abilities. Maslow suggested that the approach taken to meet the need for self-realization varies from person to person. The need for self-realization is to strive to realize your potential and make yourself increasingly the person you want to be. The key words include: realizing personal potential, self-fulfillment, seeking personal growth and peak experiences.

Maslow's hierarchy of needs theory reveals the common law of human behavior and psychological activity. Maslow explores human motivation and studies human behavior from the perspective of human needs, and points out that human needs are constantly evolving from lower level to higher level. Therefore, the hierarchy of needs theory has an enlightening effect on research the trend of clothing demand.

2.2.2 Enlightenment of Maslow's theory on clothing demand

In human social life, there may be no more vivid expression of people's value orientation and way of life than the choice of dress. This study analyzes the embodiment of Maslow's hierarchy of needs theory in the trend of clothing demand from five aspects as follows:

- 1) First of all, people need to survive, and human needs affect people's behavior. A person's physiological needs for food or keep thermal comfort are the first to meet the needs of all requirements. For a person who cannot fulfill his physiological needs, clothing is just for them to keep warm and shame. When a person's needs at a certain level are met at a minimum, a higher level of needs will be pursued. So this is the minimum level of demand from the market because consumers only require clothing products with a general function of shading and warming.
- 2) If the physiological needs are relatively satisfied, there will be a kind of safety need, which manifested in the hope that people want to live and work in a safe and orderly environment, with stable occupation and life security. If the security needs are not satisfied, people will have a sense of threat and fear. With the gradual rise of demand, clothing has gradually evolved from warmth function into a tool to protect their bodies and an ornament. At this time, the clothing market only needs to satisfy part of the consumer market, which has requirements for "safety". Consumers pay attention to the impact of clothing products on the body, such as ski suits and climbing shoes with special features and defensive functions, which are what they need.
- 3) With the highly developed modern society and economy, people no longer work and live just for food or clothing, and people have the free choice of purchasing and the preference for clothing. The dress of freedom makes the relationship between individual wearing

behavior and self-expression more closely related. The purpose of human dressing is usually summarized as protection, etiquette, and decoration, while the purpose of etiquette and decoration is closely associated fashion.

With the rapid development of society and the acceleration of life rhythm, clothing has also played a distinct role in displaying human personality and psychological conditions. People are eager to be recognized by society whenever and wherever they are. If a person's physical and security needs are well met, there will be a need for love, emotion, and belonging, that is, social needs. Social needs are reflected in clothing: in school, students have school uniforms; in the company, employees have work clothes; in the evening party, there are charming and noble evening clothes; before bed, there are pajamas. At this time, the choice of clothing is expressed as a desire to have a harmonious relationship with peers and colleagues or to maintain a friendship, or belong to a group and become one of them. This is the role that clothing plays in social needs. So at this time apparel company began to introduce a variety of social functions of clothing to meet the "communication" requirements of the market, such as a variety of uniforms, suits, professional clothing design, these are consumers concerned about whether the product helps to improve their communicative image requirements.

- 4) People need self-esteem and the desire to gain respect from others and hope that personal abilities and achievements could be recognized by society. Clothing in the need for people to show: can be designed to sell their satisfaction, self-confidence to gain the respect of others.

The clothing we choose can project our thought, impressions, and ambitions. Business people, for example, they will bring their confident appearance and feel with the latest style or most expensive suits for attending important meetings. At this time, clothing can be used to overcome the anxiety about external appearance or abilities, to help them integrate into the environment and social occasions more confident, can also win respect from others. The physical and safety needs of a senior employee who is wearing high-end fashion brand does not inspire her interest in high-end fashion. Her interest in high-end fashion may come from her status as a professional woman, as consumers seeking to respect demand is more concerned about the symbolism of the product.

- 5) In modern society, the changing way of lifestyle has become a significant factor affecting the clothing culture, and clothing was once a symbol and logo to distinguish people's social status and rank.

Through a person's clothing, we can "see" their social status, economic status, political tendency, national affiliation, lifestyle and aesthetic taste. So clothing is a visual language of communication, it can tell us what kind of people the wearer is. This kind of person's demand for self-actualization is also extreme in the performance of clothing. When physiological needs, safety needs, social needs, and respect needs are met, people will need

to achieve self-actualization, manifested in the desire to maximize their ability or potential through their efforts. For example, to achieve self-actualization through the pursuit of luxury brand clothing or private custom-made haute couture.

2.2.3 The relationship between Maslow's hierarchy of needs and clothing needs

By horizontal comparison, we found that the five symbolic attributes of clothing exactly match the five needs of Maslow's pyramid model (Table 4). The properties meaning of the two models from 1 to 5 levels are entirely reciprocal and synergistic (Figure 13). This discovery can lay a theoretical foundation for the follow-up research of interactive clothing subject. That is, the study of smart clothing should take the essential attributes of clothing as the theoretical support.

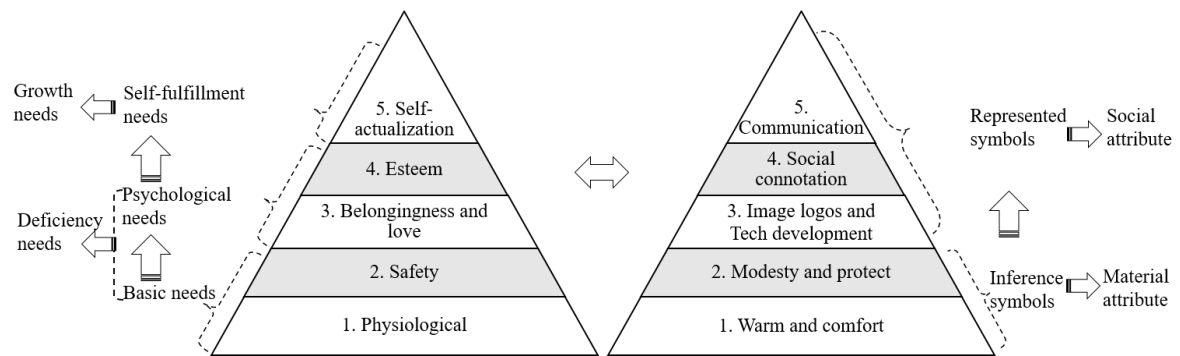


Figure 13. The synergy of clothing needs and Maslow's hierarchy of needs

Table 4. Comparison of Maslow's hierarchy of needs and Clothing needs

Level	Maslow's hierarchy of needs	Clothing needs
5	Self-actualization: realizing personal potential, seeking personal growth and peak experiences.	Communication: luxury fashion or haute couture, distinguish social status.
4	Esteem: achievement, mastery, independence, dominance, prestige, self-respect, and respect.	Social connotation: bring confident appearance; project thought, impressions and ambitions.
3	Belongingness and love: friendship, intimacy, affection.	Image logos: clothing displaying human personality and relationship with a group.
2	Safety: health and wellness, shading body, safety against accidents and injury.	Modesty and protect: consumers pay attention to the impact of clothing products on the body.
1	Physiological: for human survival, such as food, clothing, shelter and clothing.	Warm and comfort: clothing with a general function of shading and warming.

2.3 The hierarchy and typology of clothing design

Bian (1998), Waddell (2004) and Chevalier & Mazzalovo (2012) have explained why the clothing industry divides into three levels as Ready-to-Wear, High-grade Ready-to-Wear, and Haute Couture. As Waddell, G. once pointed out:

The levels of the fashion industry are really levels of manufacture, couture being the highest level and most time-consuming especially in terms of skilled labour, the number of repeat items being only in the tens or twenties. Ready-to-wear or pret-a-porter companies manufacture at a very high level, hut industrially and in multiples of hundreds or thousands. Mass production is the cheapest and most highly industrially and can produce hundreds of thousands to millions of garments (Waddell, 2004, pp. X).

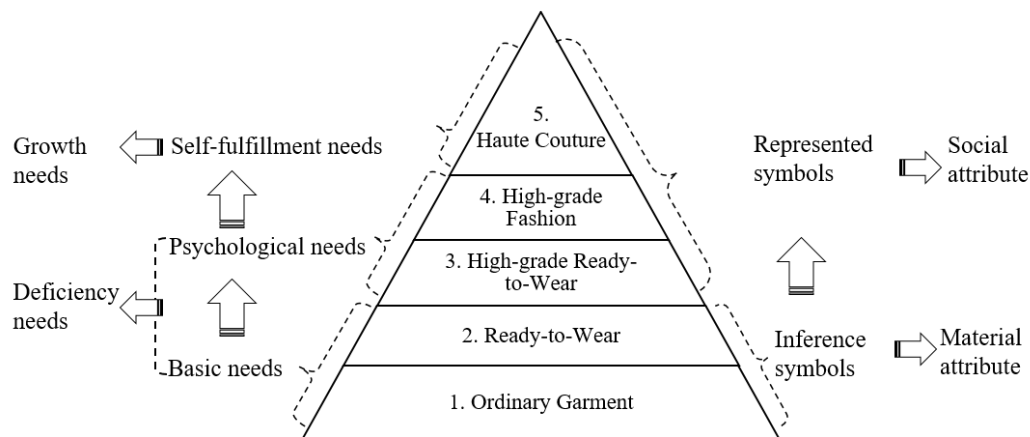


Figure 14. Hierarchy and typology of clothing design

However, slightly different from these scholars' views, this study integrated the design and production characteristics of clothing as well as the analysis perspective of the market distribution cluster hierarchy (Figure 14), clothing can be divided into Ordinary Garment, Ready-to-Wear, High-grade Ready-to-Wear, High-grade Fashion and Haute Couture, five categories ranging from low level to high level as follows:

1) Ordinary Garment

Ordinary clothing, which just provides the basic material function of clothing and does not attach to any design meaning, is also the cheapest clothing category for the mass market.

2) Ready-to-Wear (Mass Ready-to-Wear)

Ready-to-Wear products are clothes produced according to certain specifications and sizes. They are characterized by simplicity, beauty, practicality and short fashion cycle. It is generally divided into High-grade Ready-to-Wear and Mass Ready-to-Wear two types (Jiang, 2011). Mass Ready-to-Wear clothes refer to the clothes produced in large quantities and standardized with the general public as the object of consumption. But there is also a

relative lack of design characteristics.

3) High-grade Ready-to-Wear

High-grade Ready-to-Wear refer to clothes between high-grade fashion and Mass Ready-to-Wear, with the middle class as the object of consumption, small batches, and many varieties style. The difference between High-grade Ready-to-Wear and Mass Ready-to-Wear lies not only in their price, batch production and quality, but also in their design personality, taste and brand sense of belonging (Jiang, 2011).

Similar to Couture Fashion, High-grade Ready-to-Wear is also emphasis on custom made. The difference lies in that High-grade Ready-to-Wear emphasizes clothing can be produced in small batches of mechanized production and can be targeted at more consumers.

4) High-grade Fashion

High-grade Fashion, i.e., senior fashion customized by designer, while also emphasizing creativity and originality, embodying the characteristics of pop and fashion to provide customized design services for niche customers.

In the middle of last century, with the rapid development of independent clothing industry in the United States, Britain, and other countries, Haute Couture also conforms to the trend of the times, and gradually derives High-grade Fashion clothing industry and High-grade Ready-to-Wear clothing industry.

5) Haute Couture

Haute Couture, the highest honor in the fashion industry, is only qualified to own a fashion workshop which has been awarded the title of “Haute Couture” by the Federation Francaise de la Couture. At present, there are only over 10 Official Members in the world such as Alexandre Vauthier, Alexis Mabille, Bouchra Jarrar, Chanel, Christian Dior, Christophe Josse, Franck Sorbier, Giambattista Valli, Givenchy, Jean Paul Gaultier, Maison Margiela, Stéphane Rolland, and Yiqing Yin.

The rules for Haute Couture membership are as follows: First of all, all fashion and accessories are designed and manufactured for private customers. Secondly, there must be a workshop in Paris, which has at least 15 full-time staff and employs more than three full-time models perennially and emphasize the use of manual completion of high-grade traditional crafts. Thirdly, the members should attend two high-end custom fashion exhibitions held by the Federation Francaise de la Couture in January and July each year, with no less than 35 sets of daily and evening clothes being released each season.

In France, Haute Couture enjoys a high social and cultural status and is considered the eighth art after literature, drama, painting, music, dance, sculpture and film. The Haute Couture has creative, artistic, ideological and forward-looking artistic characteristics. Designers use the unique elements of clothing to create. They sublimate themselves with creative ideas, three-dimensional exaggerated styles, high-grade and novel fabrics,

colorful layers, exquisite and complicated crafts, luxurious and beautiful decoration. The form and connotation of clothing, endow clothing with a new artistic perspective and expand the scope of modern art. It stands at the top of fashion, its unique artistic tension and advanced aesthetics have a strong guiding role for the whole fashion trend.

The prices of Haute Couture are super high, and there are not many customers around the world who can afford Haute Couture, which proves that only Haute Couture can genuinely reach the highest level of “self- actualization needs” on clothing.

Similar to most industries, fashion requires innovation to survive and thrive; innovation depends on designers’ creativity and original ideas to drive change, which is the reason for maintaining market continue to grow healthily and be attractive. As a result, Haute Couture, with its creativity, scarcity and high value-added, ranks at the top of the category hierarchy pyramid and leads the design of other types of clothing and market development.

These five levels are perfectly consistent with the clothing’s symbolic attributes and Maslow’s hierarchy of needs (Figure 15). This verifies that the result of analyzing the hierarchy and category of clothing design is correct.

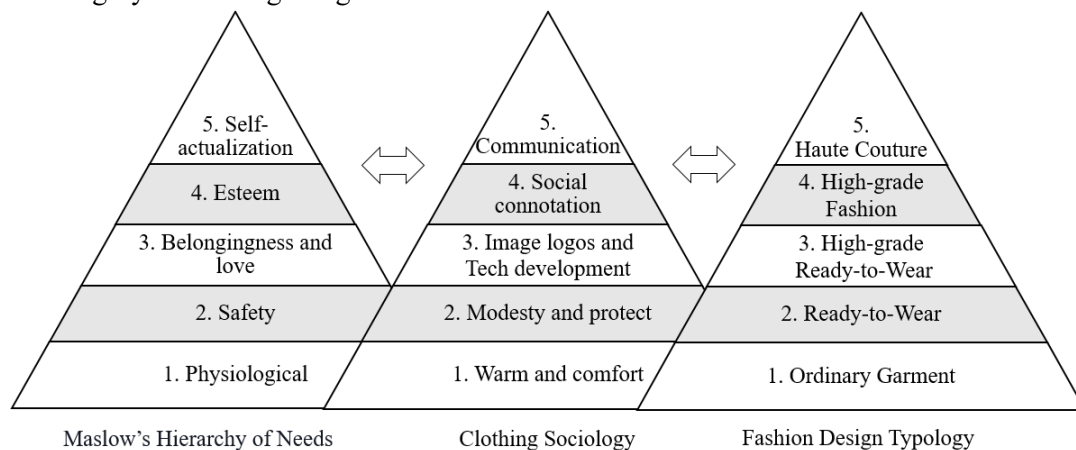


Figure 15. The synergy of Maslow’s hierarchy of needs, clothing needs and clothing design

2.4 Deduce the evolution trend of interactive clothing—IoC

From an evolutionary perspective, interactive clothing has obvious potential applications. As can be seen from Figure 16, the future development of this field can be divided into three evolution stages according to my previous research (Wang et al., 2018a).

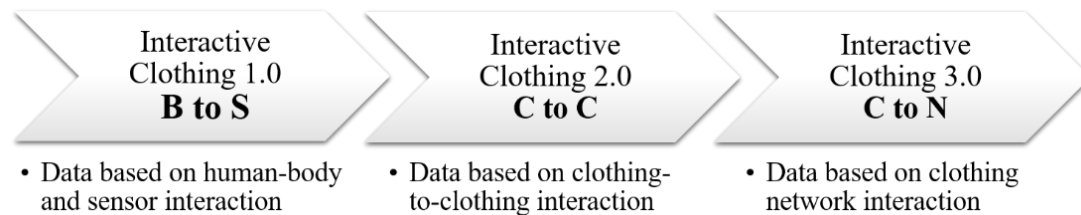


Figure 16. The interactive clothing evolutionary roadmap

- Interactive clothing in stage 1.0: Data on the human-body obtained via sensor monitoring (B to S). The clothing responds to the human physiology, such as the pulse, temperature, humidity, and even emotional reactions. At present, we can see some of the latest research results of healthcare clothing (Joo et al., 2016; Mana et al., 2016; Jagelka et al., 2016), these fruitful studies belong to the 1.0 stages of the evolution of smart clothing.
- Interactive clothing in stage 2.0: The data exchange based on clothing-to-clothing interaction (C to C). Using stage 1.0 as a basis, mutual reactions between two pieces or a series of clothing can be obtained to develop a new dynamic language of wearable expression, such as responses to the mutual distance and other interactive reactions.
- Interactive clothing in stage 3.0: The data exchange based on clothing-to-network interaction (C to N). Based on stage 2.0, the interactions realized between multiple items or a series of clothing, thus allowing the formation of a clothing network. That is, stage 3.0 is the Internet of Clothes (IoC, reference to the concept of the Internet of Things) formed on the basis of the IoT technology platform. Through the 3.0 stage of interactive clothing, people can connect the virtual network and the real scene, carries on the free emotion communication, and thus constructs a smart clothing IoT as a carrier interactive chain to link wearer and things, things and things, wearer and wearer.

The association of IoT and IoC

IoT is a computing concept that contain electronics, software, actuators, and connectivity which allows these things to connect, interact and exchange data. It is describes the idea of everyday physical objects being connected to the internet and being able to identify themselves to other devices. IoT involves extending Internet connectivity beyond standard devices, such as desktops and smartphones, to any range of traditionally dumb or non-internet-enabled physical devices and everyday objects. Embedded with technology, these devices can communicate and interact over the Internet, and they can be remotely monitored and controlled. When many objects act in unison, they are known as having “ambient intelligence.” In other words, with the internet of things, the physical world is becoming one big information system.

Source:

https://en.wikipedia.org/wiki/Internet_of_things

<https://www.techopedia.com/definition/28247/internet-of-things-iot>

A thing, in the context of the IoT, is an entity or physical object that has a unique identifier, an embedded system and the ability to transfer data over a network. Given the prevalence of wireless technology, the increasing ability to miniaturize computer components and develop them inexpensively, that capacity could be developed for almost anything imaginable. In addition to dedicated computing devices such as PCs, smartphones or tablets, the list of

potential things is almost unlimited. Clothing is of course also in this list, that is, internet of clothes (IoC).

The difference between IoT and IoC

Application innovation is the core of IoT development, user experience is the soul of IoT development.

- IoT is a technology interaction platform; IoC is an application innovation and technology extension of IoT, is a humanistic interaction platform.
- IoT is an information network that transmits technical information; IoC emphasizes the clothing network that transmits the symbols of humanistic emotion.
- IoT is mostly used in industrial production, while IoC emphasizes a future clothing lifestyle.
- IoT belongs to the technology system of technical category, and IoC is the humanistic evaluation system belonging to the social category.

Based on the above deduction, we can outline its development path from the perspective of clothing function as shown in Figure 17. It can infer the conclusion that the development path of clothing evolves from the ordinary everyday clothing to the functional clothing, the smart clothing, the interactive clothing and the internet of clothes. The focus of the combination of the smart clothing concept and IoT technology is the display form of interactive clothing and IoC.

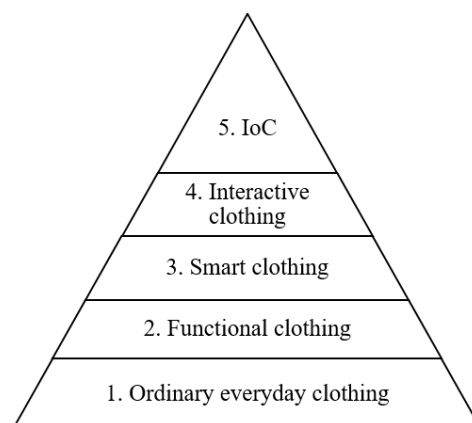


Figure 17. The evolution of clothing function

From the perspective of clothing function evolution (Figure 18), the pyramid level in this cyber world complete correspondence with the level of Maslow's hierarchy of needs, clothing sociology, psychology and market demand. All four categories evolved from low-level to advanced level, but within the horizontal comparison range, each level performs similar structure tasks and functions relationship. This verifies that the result of analyzing the evolution path of the clothing from a functional perspective is correct.

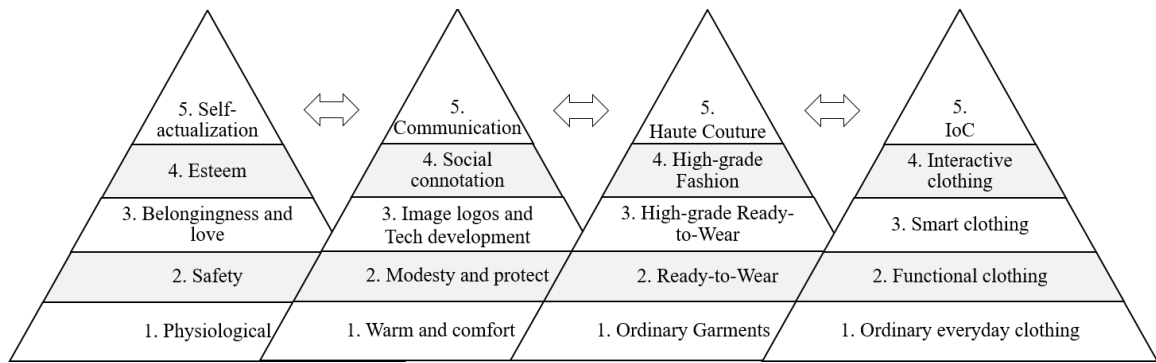


Figure 18. The synergy of clothing function categories with psychology, sociology and market trends

2.5 The relationship between DIKWS and the evolution of clothing function

In the domain of information theory construction, when it comes to smart or interactive clothing, it is inevitable to trace to the IoT data theory hierarchy model, i.e., data-information-knowledge-wisdom-service (Figure 19. DIKWS, for short) (Rowley, 2007; Frické, 2009).

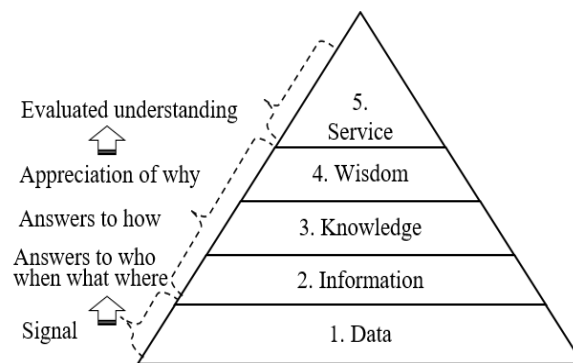


Figure 19. The DIKWS hierarchy (after Rowley, 2007; Huang, 2014)

Zins (2007) summarized the formulation of systematic conceptions of data, information, and knowledge is essential for the development of the information science and knowledge management.

Data is a series of disconnected facts and observations. These may be converted to information by analyzing, cross-referring, selecting, sorting, summarizing, or in some way organizing the data. Patterns of information, in turn, can be worked up into a coherent body of knowledge. Knowledge consists of an organized body of information, such information patterns forming the basis of the kinds of insights and judgments which we call wisdom. The above conceptualization may be made concrete by a physical analogy: consider spinning fleece into yarn, and then weaving yarn into cloth. The fleece can be considered analogous to data, the yarn to information and the cloth to knowledge. Cutting and sewing the cloth into a useful garment is analogous to creating insight and judgment.

Huang et al. (2014) expanded the previous research results and proposed the concepts of W2T cycle and wisdom as a service in conjunction with the cyber and Hyper world. The DIKWS refers to:

“the data transformation from raw data acquired in the physical world to information, knowledge, and wisdom in Cyber world, and the data circulation of Things → Data → Information → Knowledge → Wisdom → Service → Human → Things in the Hyperworld, combining the physical world and Cyber world. ... adopt a from data-to-wisdom data analysis and knowledge fusion platform called Wisdom as a Service to mine knowledge which leads to the wisdom for providing services from huge amounts of data. In this platform, there are three layers: structured data, information, and knowledge, and each layer can provide services as: data as a service, information as a service, knowledge as a service, and wisdom as a service on the whole.”

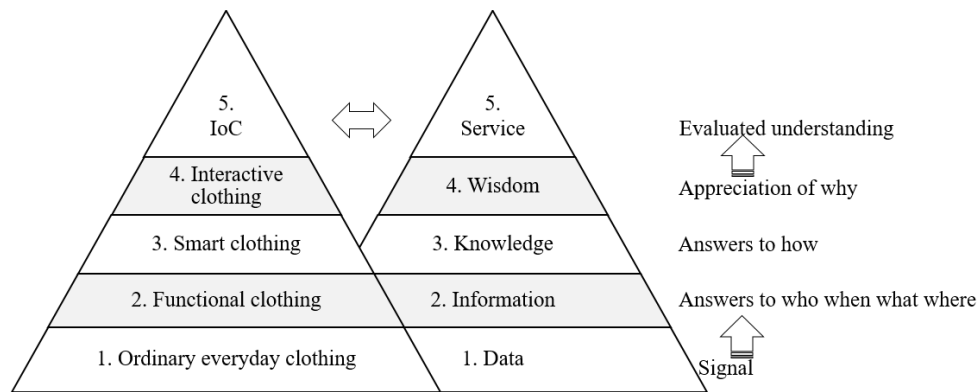


Figure 20. The consistency between the hierarchies of DIKWS and TFSII

Table 5. Compare the development process of DIKWS with TFSII

Level	DIKWS	TFSII
5	Service: combining the physical world and Cyber world	IoC: clothing-to-network interaction, network symbols
4	Wisdom: appreciation and evaluation of “why”.	Interactive clothing: a carrier that forms the interpersonal interaction symbol in daily life.
3	Knowledge: application of data and information; answers “how” questions.	Smart clothing: embed CPS to form intelligent feedback.
2	Information: data that are processed to be useful; provides answers to “who”, “what”, “where”, and “when” questions.	Functional clothing: wear in special environments to provide security, protection, and other functions.
1	Data: facts, individuals, signals, events.	Traditional clothing: style, fabric, color, signals.

Through horizontal comparison (Figure 20), we can find the corresponding relationship between DIKWS and the evolution of clothing function in each development stage from the level 1 to 5 (Wang et al., 2018b). The development process of data-information-knowledge-wisdom-service hierarchy and traditional-functional-smart-interactive-IoC (TFSII, for short)

hierarchy is very consistent. They have the same attributes or complete the same types of the task at each development level (Table 5).

2.6 The relationship between CPS/IoT and clothing

2.6.1 Concept of the IoT

In addition to the introduction in 2.4, the IoT can be perceived as a far-reaching vision with technological and societal implications. From the perspective of technical standardization, the IoT can be viewed as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

According to the definition of the International Telecommunication Union (ITU, Y.2060), the IoT mainly solves the interconnection between Thing to Thing (T2T), Human to Thing (H2T), and Human to Human (H2H). Essentially, the interaction between human and machine, machine and machine is mostly to achieve the interaction of information between people.

2.6.2 Concept of the CPS

Cyber-Physical Systems (CPS) is usually defined as a tight integration of computation, communication, and control with a deep interaction between physical and cyber elements in which embedded devices, such as different sensors and actuators, are wireless or wired networked to sense, monitor and control the physical world (Lee, 2010, 2015).

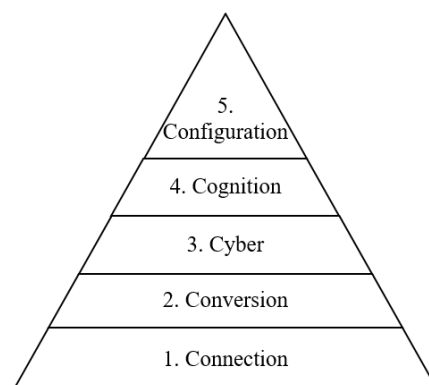


Figure 21. The 5C architecture of CPS (Lee et al., 2014; Ning, 2016)

In the domain of information technology executives, when it comes to interactive clothing, it is inevitable to trace the architecture of CPS. Since Lee (2008) and Cardenas (2008) proposed the 3C infrastructure of CPS, the CPS architecture has been continuously improved. According to the architectural model proposed by Lee et al., (2014), Ning et al., (2016), Lee (2015) and

Longo et al., (2017), the 5C architecture of CPS could provide conceptual guidance for the development of interactive clothing (see Fig. 21).

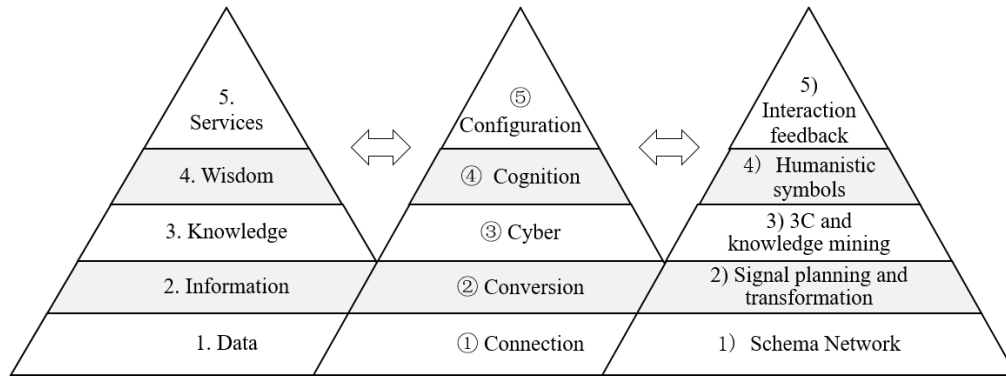


Figure 22. The consistency between the hierarchies of DIKWS, 5C and the technical process of the interactive clothing

Through horizontal comparison (Figure 22), we can find the perfect correspondence relationship between DIKWS, 5C architecture of CPS and the technical process of the interactive clothing in each development stage from the level 1 to 5, as details in Table 6.

5C architecture can provide conceptual guidance for interactive clothing development. At the same time, according to level 4 in Table 6, the humanistic design and evaluation of interactive clothing can inject humanistic vitality into the seemingly cold information technology, making it feasible for CPS to introduce people's daily emotional life. This also part responded to MRQ and SRQ2 mentioned in Chapter 1.

Table 6. Comparison of the technical process of the 5C and interactive clothing

Level	5C architecture of CPS	Technical implementation details of interactive clothing design
5	Configuration: self-configure, self-adjust, self-optimize; distributes the instructions.	Interpersonal interaction; symbolic-message; humanistic feedback to clothing.
4	Cognition: identify and make decisions, analyze task goals and status; collaborative optimization; knowledge generation.	Integrated simulation and synthesis of humanistic symbols; identify evaluation indicators; collaborative diagnostics and decision.
3	Cyber: data computing, distribution, decision and control of CPS system; data and knowledge mining.	Computing, communication, and control of clothing cyber performance diversity.
2	Conversion: Machine-based Algorithms; local intelligence; data conversion into useful information.	Signal planning, sensing, and transformation; specific algorithm.
1	Connection: sensor network; information collection and communication between devices.	Materials, style, and color; sensors, chips, and microprocessors.

From the signals sent by the wearer or clothing (Table 6. Level 1 and 2) to the humanistic

symbols observed or perceived by the relevant parties (Table 6. Level 4 and 5), this evolutionary process is inseparable from the support of cyber. This is part responded to SRQ2 in Chapter 1. The evolution from information to knowledge requires the introduction of humanistic consciousness and symbols as a medium of evolution (Fig. 22. Level 4). This also part responded to SRQ2 mentioned in Chapter 1.

This 5C architecture is still a conceptual model, not specific enough to guide the development of interactive clothing.

2.7 Other associated terminologies

2.7.1 Technology-centered design and human-centered design

“Human-centered” originates from philosophical thought but not humanism. It refers to the most basic starting point of considering all the interests and needs of human beings in the design as the measure of the result of activities. Today’s design community, the design of “human-centered” has almost become the “golden rule”. The fundamental purpose of design is to deal with the relationship between human beings and things.

Krippendorff (2006) proposed several dimensions turn from technology-centered design to human-centered design:

“From the design of products to the design of artifacts that can play various social roles.

From a belief in technological progress to a concern for artifacts that are supportive of communities of users and are user-friendly for their individual members.

From culture-free conceptions of design in a universe to an acknowledgment of the role of language in the construction of diverse community-specific worlds.

From imposing intended functions of products to allowing people to use them in their own terms.

From designers as a lone genius or authority to designers who can work in teams to enroll the stakeholders of their designs in joint projects.

From an attention to objects, products, material artifacts (an ontology), to an awareness of the processes of constructing and reconstructing (ontogenesis or design) artificial worlds whose sole purpose is to make sense to us, remain useful and enable us to feel at home with them”.

Source: Krippendorff, K. (2006). The semantic turn : A new foundation for design. London, New York: Boca Raton. pp.36

In the historical process of smart clothing development, the R&D concept which emphasizes technology as the core in pursuit of scientific and technological intelligence effect

has always been dominant. Krippendorff's point of view provides a clear guiding direction for solving the contradiction between technology and art design in the process of interactive clothing development.

2.7.2 Emotional design

Desmet(1999, 2009) and Norman(2004) have raised the research topic of emotion and design. Norman asserts that the emotional side of design may be more critical to a product's success than its practical elements. His emotional design model with three levels:

- Visceral (lowest level) which embodies the sensory aspects of how things look, feel, smell, and sound.
- Behavioral (middle level), at which users form their perceptions of a particular product through use.
- Reflective (top level) is the level at which the product has meaning for consumers; it accounts for how consumers maintain an innate sense of identity through the consumption of the product over time.

Smart clothing also belongs to the field of artificial intelligence. Artificial intelligence can assist humans and help them perform tasks better, but still lacks a certain cognitive quotient and giving people a sense of apathy. The R&D of interactive clothing needs to inject humanistic emotion reflective elements.

2.7.3 Kansei engineering

Kansei engineering, founded by Professor Mitsuo Nagamachi, a methodology within the research field of affective engineering, aims to develop or improve products by transforming the customer's physical and psychological needs into the domain of product design parameters.

This method is helpful to understand consumers' emotions accurately, to reflect Kansei understanding into product design, and to create a system and organization for emotional orientated design.

According to Nagasawa, one of the forerunners of Kansei engineering, there are three focal points in the method: How to accurately understand consumer Kansei; How to reflect and translate Kansei understanding into product design; How to create a system and organization for Kansei orientated design.

Schütte et al. (2004) developed a general model covering the contents of Kansei engineering, include the following steps: Choice of Domain, Span the Semantic Space and the Space of Properties synchronously, Synthesis, Test of Validity and Model building.

There have been many successful cases in applying Kansei engineering methods to clothing product development, so this study also adopts this method.

2.8 Summary

According to the above literature analysis and summary, it can be conclusion that there are several hierarchies and typologies of clothing R&D from humanities and technology perspective.

2.8.1 Interactive clothing conforms to the evolution trend of clothing

On the development trend and evolutionary path of clothing (Figure 23), types of clothing property, grades of clothing property, and technical grades of functioning clothing property, they all support the future development of interactive clothing. According to the symbolic semantics model of clothing in Figure 11, clothing has multiple attributes or properties: 1)Improving warmth and comfort; 2)Providing modesty and protection; 3)Displaying logos; 4)Reflecting technological development; 5)Conveying certain social and cultural connotations; and 6)Facilitating communication and expression.

- I. Physical and Sociological properties of clothing: those six properties of the clothing mentioned above can be classified as three grades of physical (①, ② and ③), social (④ and ⑤) and spiritual properties ⑥ in Figure 23. I.
- II. Grades of clothing property according to Maslow's Hierarchy of Needs: Physical properties are also basic properties include (①, ② and ③). Sociological properties include (④, ⑤ and ⑥). Among them, ④ and ⑤ belong to intermediate properties, and ⑥ belongs to the advanced property (Figure 23. II).
- III. The technical properties are mainly combined with smart technology to achieve the technical functions of clothing. Each's needs should be satisfied at the lower levels before they progress to the higher, more complex levels. Technical grades of functional clothing property include three levels (see Figure 23. III): ordinary everyday clothing belong to basic grade, with (①, ② and ③) main properties and secondary properties (④, ⑤); smart clothing belong to intermediate grade, with (④, ⑤) main properties and (①, ②, ③) secondary properties; interactive clothing belong to advanced stage, main property is ⑥ and secondary properties are (④, ⑤).
- Geppert (2012) separated the application scenarios of wearable computing into three categories: "Sensing and data analysis", "Interfaces" and "Functionality and Aesthetics".

In this research, I use the category of IoT functionality and design aesthetics to definite interactive clothing. Interactive clothing with the characteristics of fashion, one branch of smart clothes, is more emphasis on the characteristics of the clothing network with IoT system. Comprehensively, smart clothing mainly refers to technology upgrade based on the basic physical properties (①, ②, and ③) of clothing. The interactive clothing mainly refers to enhance the social properties based on smart technology (④, ⑤, and ⑥).

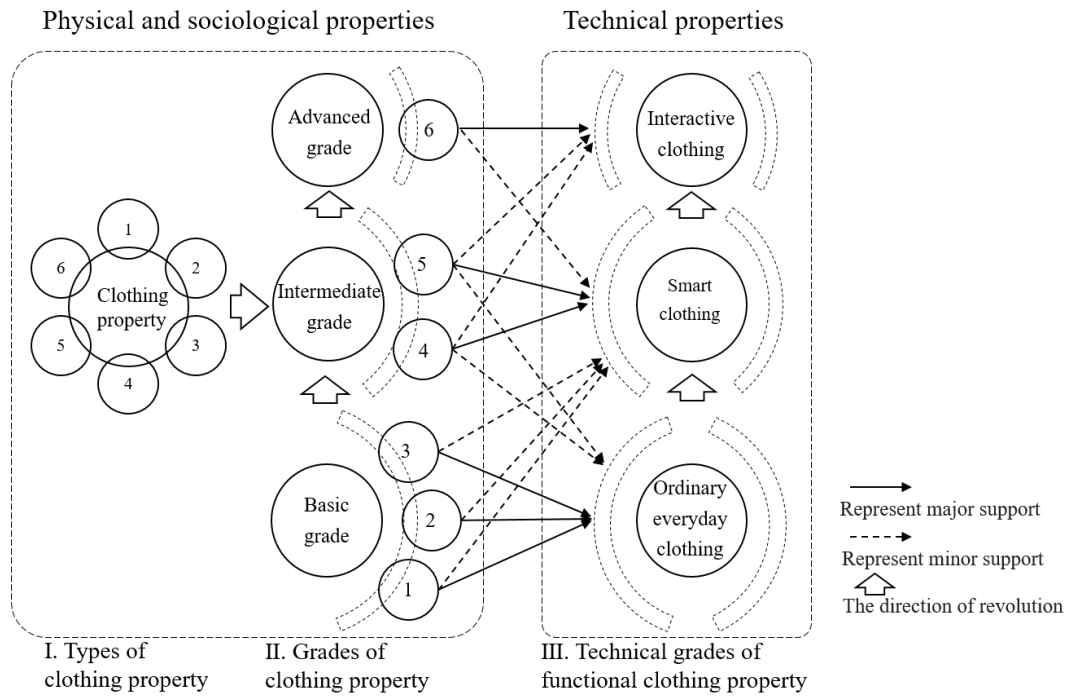


Figure 23. The interrelationships between properties of clothing and their evolutionary path

2.8.2 Humanistic and technical features of interactive clothing

Hierarchy and typology of clothing R&D from humanities and technology perspective. According to the horizontal comparison of humanistic and technical perspectives, interactive clothing is at the fourth level of two models respectively, and the transverse attribute of the level fourth is the function or characteristic of interactive clothing.

At the psychological level of humanistic perspective (Figure 24), interactive clothing needs to meet the “Self-esteem needs”, and it is necessary to satisfy the function of “Connotation” in the sociology of clothing, and it belongs to the “Couture fashion” category in clothing design typology. This model part responses to the SRQ 1 mentioned in Chapter 1.

From the technical perspective (Figure 25), interactive clothing needs to meet “Wisdom” requirements in IoT data theory, “Cognition” functionality in the 5C architecture of CPS, and the transmission of “Humanistic symbols” regarding technical processes. This model also part responses to the SRQ 1 mentioned in Chapter 1.

The relationship between each levels of the different category in Figure 25 as follows:

All four categories evolved from low-level to advanced level, but within the horizontal comparison range, each level performs similar structure tasks and functions relationship.

In the context of the level 1, they are representing stimuli or signals, objective facts or observations, which are unorganized and unprocessed and therefore have no meaning or value because of lack of context and interpretation. They are “of no use until...in a usable (that is, relevant) form” (Zins, 2007; Rowley & Hartley, 2008).

In the context of the level 2, they are inferred from level 1 and differentiated from level 1 in that they are “useful” in the process of answering interrogative questions (e.g., “who”, “what”, “where”, “how many”, “when”) (Bellinger, Castro, & Mills, 2004), thereby making the data useful[28] for “decisions and action” (Liew, 2007). Level 2 is defined as they are endowed with meaning and purpose.

In the context of the level 3, they are defined with reference to level 2. Definitions may refer to the context of level 2 having been processed, organized or structured in some way, or else as being applied or put into action.

In the context of the level 4, they are described as “know-why” (Zeleny (2005), so as to differentiate “why do” from “why is”, and expanding the definition to include a form of know-what (“what to do, act or carry out”). And these will bring enlightenment to the level 5, as well as represents evaluated understanding.

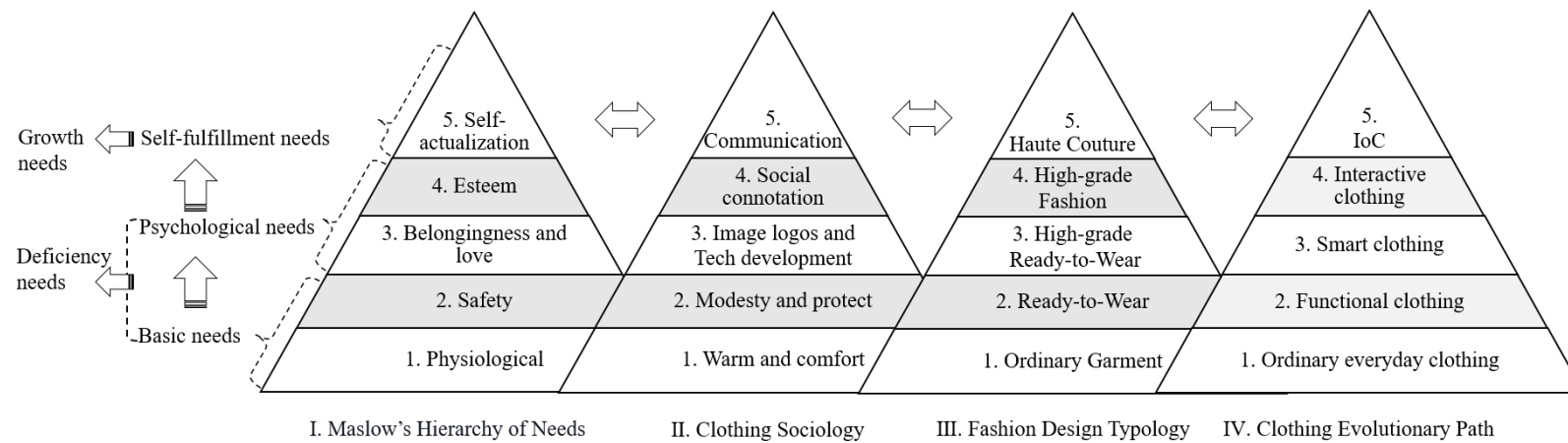


Figure 24. Evolutionary route based on psychology, sociology, and design (Humanities)

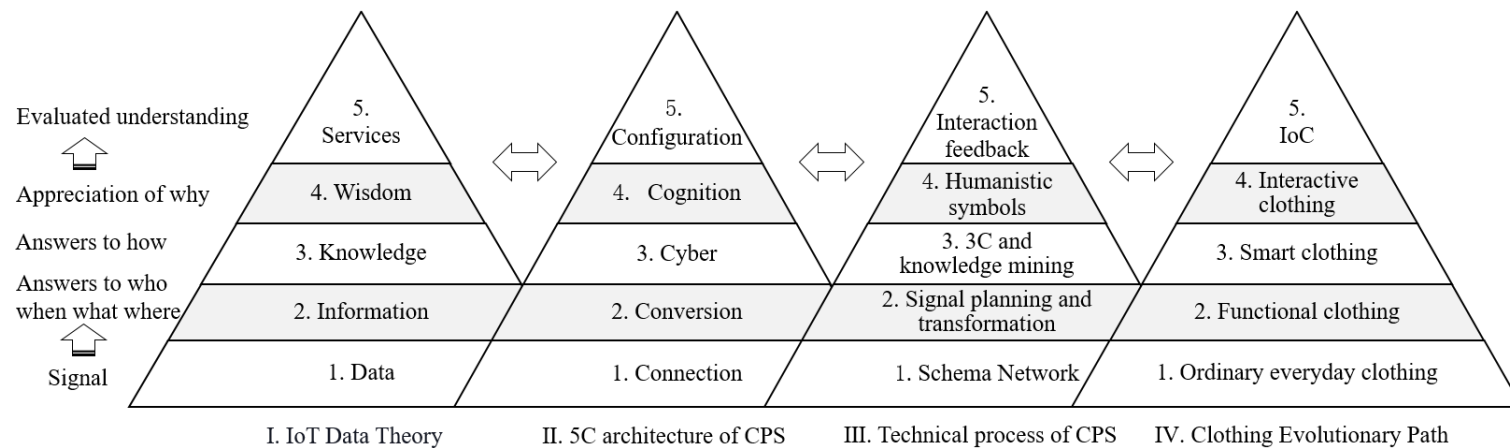


Figure 25. Evolutionary route based on IoT and CPS applications (Technology)

Chapter 3

Research Model and Methodologies

3.1 Research roadmap

According to the research aims, objectives, and the research questions of this study mentioned in Chapter 1, if we want to explore what happened in the process of realizing interactivity of interactive clothing and what technical means were used in this process, then we need to disassemble and analyze the technological flow of interactive clothing R&D.

The research roadmap, according to Soft System Methodology, i.e., the “WHY”, “HOW” and “WHAT” shown in Figure 26. WHY: This factor investigates the reasons why interactive clothing should satisfy technical functions and human emotional expression simultaneously. This problem cannot be separated from the grades of clothing symbolic properties mentioned in Figure 23, that is, clothing has multiple attributes or properties: 1)Improving warmth and comfort; 2)Providing modesty and protection; 3)Displaying logos; 4)Reflecting technological development; 5)Conveying certain social and cultural connotations; and 6)Facilitating communication and expression.

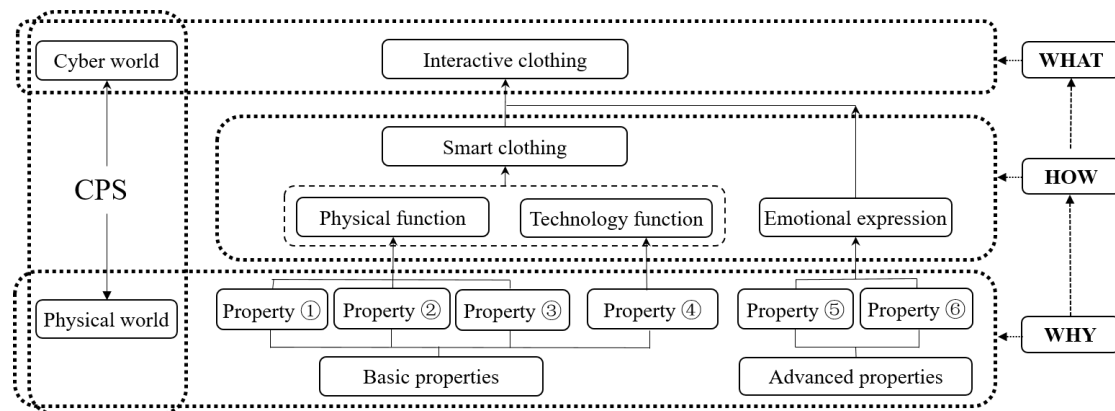


Figure 26. Research roadmap

HOW: This factor refers to disassemble and analyze the technical process of interactive clothing design and development, investigates the manner in which artistic design perspectives and engineering methods can be effectively combined, blending emotional communication with IoT/CPS technology in the form of interactive fashion innovation. WHAT: This factor refers to the R&D elements of interactive clothing in the context of cyber world based on IoT/CPS

technology. Therefore, the research roadmap should revolve around the CPS' deep interaction between the physical world and the cyber world, and explore the relationship between why, how and what factors.

3.2 Creating the CPCS research model

Using the three factors “WHY,” “HOW” and “WHAT” mentioned above, an innovative systems architecture is developed for interactive clothing.

The technical process of interactive clothing design and development can be summarized from the three models (Figure 23, 24, and 25) mentioned in Chapter 2. The technical relevance of interactive clothing, DIKWS, and CPS was revealed in the Cyber-Physical-Clothing Systems (CPCS) model (Figure 27). Response to the MRQ of this research, this model can explain what happened and how do the social semantics of the interactive clothing transform from the information stage to the knowledge stage in the architecture of CPS.

The role of this model is to explain the technical development process of interactive clothing from clothing to data, information, knowledge, wisdom, services, humans, and then back to clothing (the Clothing to Human cycle, C2H for short) in the perspective of CPS and DIKWS architecture.

The interactive clothing has the characteristics of information processing and human feedback, it is controlled by machine-based algorithms and integrated the network with its wearers into one unified and holistic framework, which determines its interactive architecture, like other scholars' research results, can be divided into three levels: physical level, cyber level and social level (Sheth et al., 2013; Rajkumar et al., 2010). The vertical direction in this model represents the functional relationship of progressive interaction from physical level to cyber and social level, and the horizontal direction corresponding is the technical principle relationship in three levels between C2H technical implementation (inside the blue dotted box), DIKWS, and CPS loops (inside the red dotted box). The dotted double arrows represent interactions and effects, and solid line wide arrows represent development directions.

3.2.1 Technical processing of interactive clothing at the physical level

The entity item of the physical level is clothing.

- 1) This level is implemented by embedding the sensors and microprocessors in combination with the style design of the clothing to create a network, performing the data connection from the clothing material or devices and forms particular signals, and finally implementing the signal conversion to the cyber level utilizing sensing.

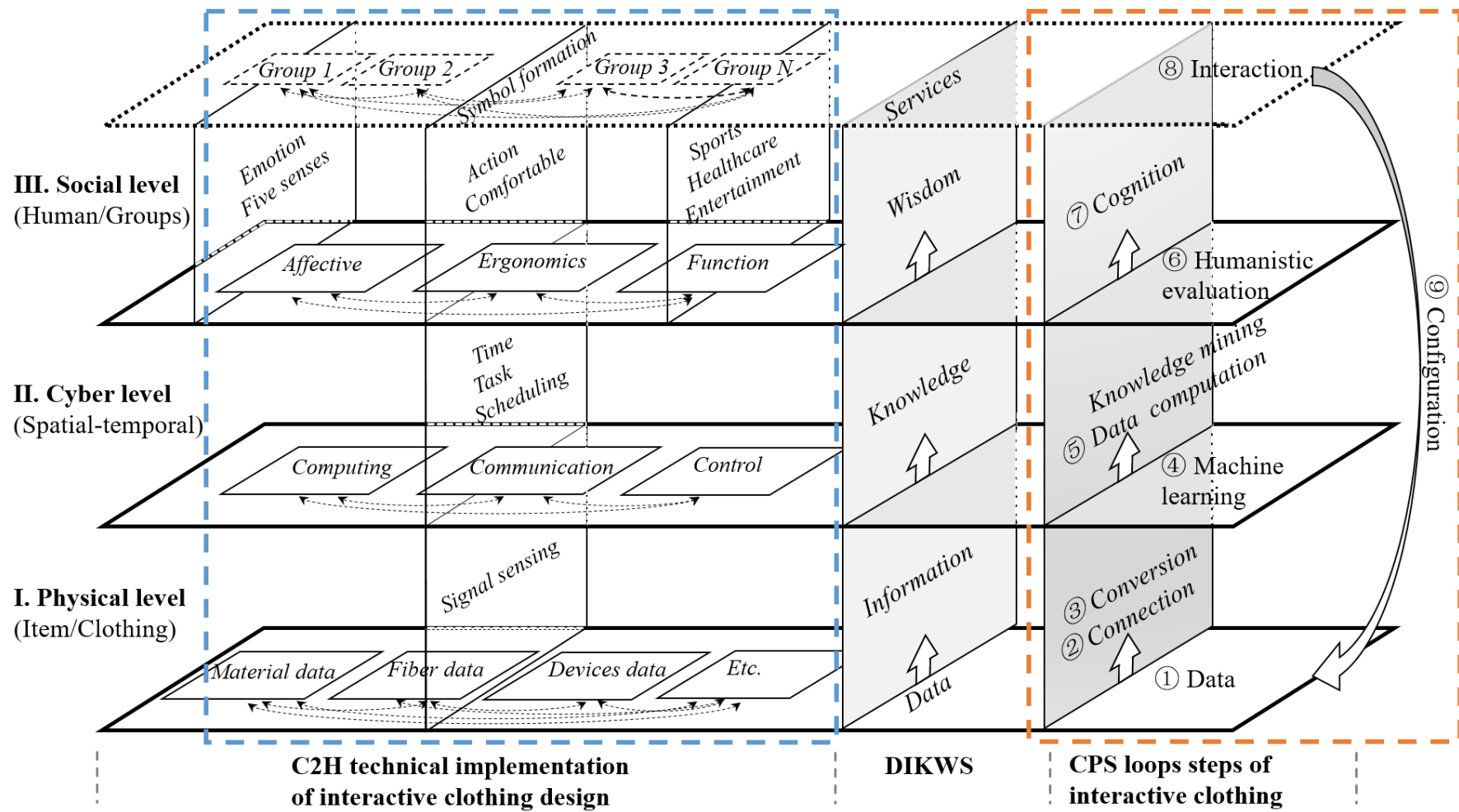


Figure 27. A CPCS architecture for interactive clothing in the hyper world

- 2) The characteristic of the process from step ① to ②③ is the informatization process from the fundamental data of the physical level of clothing to the cyber level.
- 3) The contents of this process.
 - a) Among them, the process from step ① to ② belongs to IntelliSense. The core of this process is the creation of a CPS architecture that allows data to be measured and aggregated in various forms, and the communication between embedded sensors and other devices is also possible.
 - b) Among them, the process from step ② to ③ is information mining. The core of this process is the Machine-based Algorithms on the device side so that some data can be analyzed and utilized locally in the device to achieve local intelligence.
- 4) There are also interactions between different categories of data.
- 5) The technical difficulty at this level is the transformation from connection to conversion.

3.2.2 Technical processing of interactive clothing at the cyber level

The cyber level represents the spatial-temporal concept of clothing in the process of interactive information processing. It is the information technology processing stage in the process of transforming physical signals into humanistic symbols.

- 1) The cyber level, which covers steps ④ and ⑤ in the CPS process, is the core of data processing, distribution, decision making, and scheduling control of the entire clothing CPS system. Here, a big data environment originated from clothing or wearer, while running advanced analysis algorithms for large-scale computing and knowledge mining.
- 2) The content of this level is the organic integration and deep cooperation of computing-communication-control employing time, task and scheduling, and achieves a deep combination of the cyber and physical world involving the object mechanism, environment, and group.
- 3) The characteristic of this level is the process of transforming the signaling of clothing data into the symbolization of humanities knowledge.
- 4) The technical difficulty at this level is the knowledge mining based on data computation.

3.2.3 Technical processing of interactive clothing at the social level

Social level represents the humanities activities, interpersonal interaction and communication

between individuals or groups (Ning et al., 2016) with interactive clothing as the medium.

- 1) This level includes steps ⑥, ⑦ and ⑧, the main role is to evaluate, identify and feedback, decision-making for the interactive activities of clothes. By analyzing the task objectives and status exhibited by each piece of clothing in the current system, an interactive decision-making of collaborative optimization among multiple pieces of clothing is established.
- 2) Its main content is humanistic evaluation and cognitive formation. At present, the design evaluation indicators for smart clothing or interactive clothing are mainly divided into three dimensions, that is effective indicators (emotion, five senses, etc.) (Chen et al., 2017), ergonomics indicators (action, posture, comfortable, etc.) (Hsiao et al., 2015; Kim et al., 2010), and functional indicators (sport monitoring, healthcare, entertainment, etc.) (Chen et al., 2016; Kim et al., 2016a; Salim et al., 2014). The follow-up prototype evaluation in this study was adopted the emotional/Kansei evaluation method.
- 3) The technical difficulties are the formation of cognition after perform group differentiation evaluation and the guidance of symbolic interactive feedback. Because of the interaction among different wearer groups, it is necessary to meet the differentiated needs of different types of dress groups, as well as the differences in various issues and attributes among each wearer group. Different types of feedback forms are represented by different clothing external symbols. Various communication symbols that can express social message to be output during the interaction of different groups or individuals.
- 4) This process is characterized by the transformation of clothing from knowledge to wisdom and social services, and clothing becomes the carrier of automatic feedback of the wearer to the associated person or clothing.

3.2.4 Technical processing of interactive clothing on the cross-level structure

The configuration execution layer ⑨ runs through the three levels of physical, cyber and social. After receiving the decision, the configuration execution layer transforms the decision into instructions that are understood by the logic of each subsystem, and finally performs some external performance reaction of clothing by the microprocessor and sensor embedded in the clothing.

3.3 The definition of research methods

3.3.1 Practice validation and prototyping methods

- 1) Through the literature induction and deductive research methods mentioned above, the CPCS model was created.
- 2) First of all, it should practice verifying the feasibility and rationality of the application of IoT technology in clothing.
- 3) Practical verification of the possibility of clothing interaction, and ascertain the viability of the CPCS model.
- 4) Practice verifying the diversity of clothing interaction, from personal interaction to the scale of group interaction.

3.3.2 Prototype evaluation method

- 1) Identification of authoritative institutions, that is, objective evaluation method.
- 2) Kansei Engineering evaluation method, that is, subjective evaluation method.

3.3.3 Model inductive method

- 1) Analyze the design process and results of prototypes, and construct the design principles of interactive clothing.
- 2) Analyze the process and results of the evaluation, create interactive clothing evaluation criteria system, and propose qualitative and quantitative evaluation indicators.

In summary, this study will mainly adopts a variety of research methods from Deduction to Induction, Empirical, Evaluation and Abduction in a logical order. The logical relationships of research methods and verification forms are shown in Figure 28. The CPCS model is used to guide the prototype development, and the prototype is evaluated subjectively and objectively, and a new guiding model is built based on the evaluation results and the effect of the prototype. Prototypes are used to validate the CPCS model, the purpose of the evaluation is to guide the improvement of prototypes, design principles are used to validate prototypes, and evaluation systems, in turn, validate evaluation methods.

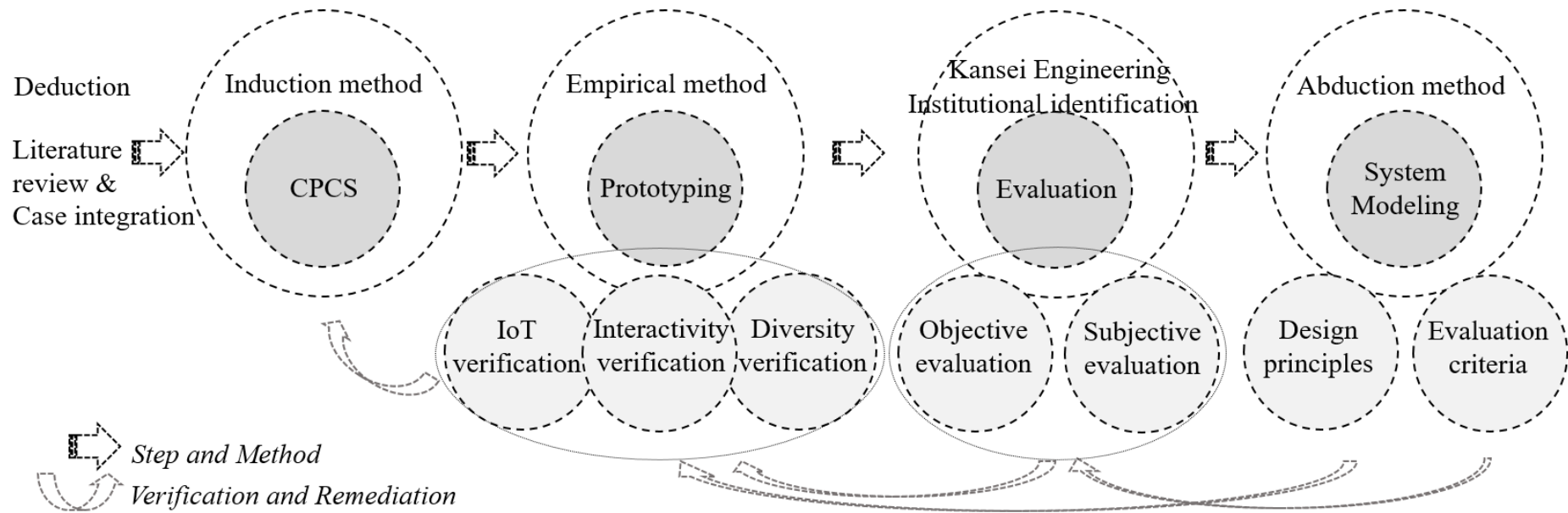


Figure 28. The logical relationships of each research method

3.4 Summary

According to the research aims, objectives, and the research questions of this study, the research roadmap of “WHY,” “HOW” and “WHAT” is proposed by Soft System Methodology.

An innovative CPCS systems architecture is developed for interactive clothing. This model is the most critical research idea for prototype development practice in this study, which lays a theoretical foundation and practical guidance for the follow-up practice research.

The technical process of interactive clothing design and development was summarized. The technical relevance of interactive clothing, DIKWS, and CPS was revealed in the CPCS model. The role of this model is to explain the technical development process of interactive clothing from clothing to data, information, knowledge, wisdom, services, humans, and then back to clothing (the Clothing to Human cycle, C2H for short) in the perspective of CPS and DIKWS architecture.

The research methods will mainly adapt Deduction, Induction, Empirical, Evaluation and Abduction, and also include prototyping method, Kansei engineering evaluation method, model verification method, and other methods of quantitative research and qualitative research. The prototype will be developed following the CPCS architecture and verified by the Kansei evaluation method, and the design principle and evaluation system of the interactive clothing will be deduced at last.

Chapter 4

Prototyping of Interactive Clothing

The practical research of this topic was started in 2012, and progressive results were getting during three stages. The first stage was in 2013, two types prototype of infant's smart clothing were developed. The second stage is which interactive couple clothing has been made from 2016 to 2017. The development of interactive parent-child clothing is the third stage from 2017. The reasons for choosing these three cases as empirical examples of this study are:

- Case 1, smart infant clothing. Analyze the feasibility of the application of IoT technology in the design and development of garment products from the perspective of sensor technology application;
- Case 2, interactive couple clothing. It is preliminary study for IoC. To bridge the gap between human emotions and wearable technologies for interactive fashion innovation, to consider the reasons why smart clothing should satisfy the IoT technical functions and human emotional expression simultaneously, to investigate the manner in which artistic design perspectives and engineering methods combined effectively;
- Case 3, interactive parent-child clothing. To bridge the gap between CPCS architecture model and emotional evaluation, to explain how the transformation could be realized from information to common feeling, to refine the design elements for interactive clothing.

4.1 Case study 1, smart infant clothing

To verify the feasibility of IoT sensing technology applied to clothing, this research completed two types of infant's smart clothing development in 2013. As a result, two China's utility model patents have been granted, which shows the feasibility and rationality of this case study. Furthermore, the fundamental study of interactive clothing has established the technical foundation by this experiment.

4.1.1 An infant's crotch humidity monitoring alarm trousers

The purpose of the experiment is to combine IoT sensing technology and infants clothing design, to develop a real-time humidity monitoring alarm the crotch trousers for infants. According to

the supernormal change of the crotch humidity, the children's guardian will receive an alarm.

4.1.1.1 The technical solutions

Referring to Figures 29, there are humidity sensor 2, signal wire 3, chip system 5, flexible zipper 4 and trousers crotch parts. Among them, the humidity sensor 2 is fixed on the crotch of infant trousers 7. Chip system 5 is put at the foot of infant trousers 7. Humidity sensor 2 is connected with chip system 5 by signal wire 3. Flexible zipper 4 is set at the crotch of infant trousers 7. Humidity sensor 2, signal wire 3 and chip system 5 are sewn into the hollow seam of inside position of infant trousers 7. They can be installed or taken out freely. The crotch spare parts are placed in the trousers bag 1 at the rear position of trousers.

The chip system 5 is equipped with a wireless sensor and wireless connection with the receiving device. The receiving device is equipped with a humidity test and displays an alarm.

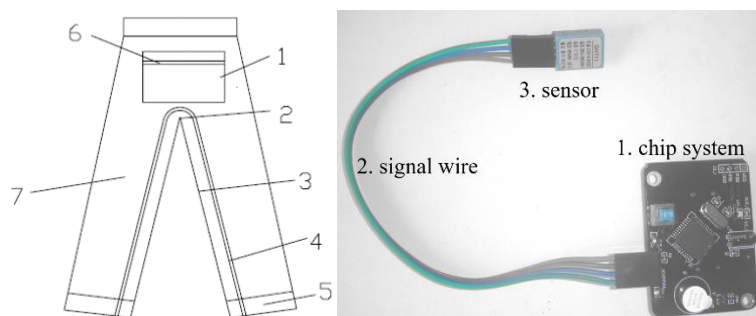


Figure 29. The structure of trousers and electronic components

When the infant's trousers are using, it is necessary to adjust the position of the humidity sensor 2 and pull the flexible zipper 4. In the event of the humidity exceeds the standard, an alarm sound will be issued, at the same time, the humidity value will be displayed digitally to remind timely replacement. The replacement process is simple, firstly the children's guardian should open the flexible zipper 4 to remove the wet diaper, then open the zipper 6 of the pants pocket, and take out the diaper from the trouser pocket 1 for replacement.

4.1.1.2 Value and significance

The humidity sensor is used to monitor the humidity of the crotch of infant's trousers at all time. As soon as the humidity was out of the setting value range, an alarm will be given by the receiving device. Meanwhile, the infant's trousers need not be replaced entirely. It only needs to open the flexible zipper to replace the wet diaper. The whole device is set in trousers and can transmit the humidity status data to the guardian through wireless signals. It avoids many tedious things in the process of monitoring infants and provides a better environment for the growth of infants, to facilitate the healthy growth of infants. The prototype and patent certificate

are shown in Figure 30.



Figure 30. The prototype and patent certificate

4.1.2 Temperature monitoring infant clothing

This purpose of this experiment is to design a real-time temperature monitoring system based on IoT sensor technology and to remind guardians to take appropriate measures according to the temperature status of infants, to better nurture infants.

4.1.2.1 The technical solutions

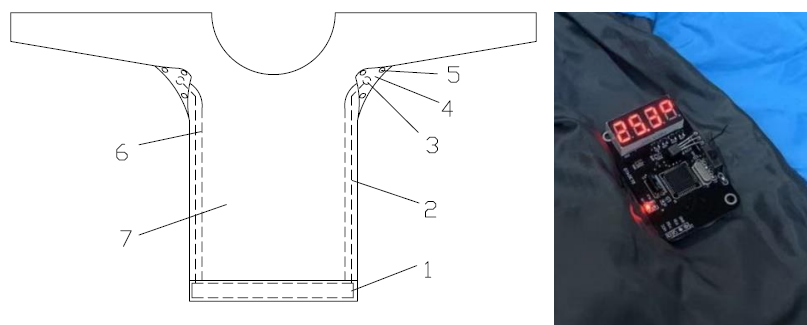


Figure 31. The garment structure and electronic components

Referring to Figure 31, there are heat-sensitive sensor 3, chip system 1, signal wire 2, underarm garment structure 4 and hollow garment seam 6. Among them, heat sensitive sensor 3 is placed in an underarm garment structure 4 of the jacket 7. Chip system 1 is installed in the hem position of the jacket 7. Signal wire 2 is set between heat sensitive sensor 3 and chip system 1. Signal wire 2 is placed in hollow garment seam 6. There is a wireless transmitter on chip system 1. The structure of electronic components can refer to Fig. 29.

There are two position of the heat-sensitive sensor 3, one is arranged in the left and right underarm garment structure 4, and the other is connected with the chip system 1 by signal wire 2. A button 5 is arranged on the underarm garment structure 4 as shown in Figure 31, which can be disassembled and installed for easy replacement and cleaning. The hollow garment seam 6 is made of the front and back garment pieces. The receiving device is placed beside the guardian, which is a sound alarm and a temperature display device that can receive wireless transmission signals.

In view of the defect of temperature detection accuracy and lack of sensitivity in the design method of non-contact body temperature detection embedded in the armpit of clothing, 10 male and 10 female children were invited from two kindergartens to carry out temperature test experiments, the body temperature of the armpit of 20 children (from A to T in Table 7) were extracted in in four states of quietness, exercising, after exercise and sleeping. Finally, the mean temperature $37.25^{\circ}\text{C}-2.25^{\circ}\text{C}$ = upper limit 35°C and lower limit 29°C was taken as the interval warning response threshold of the prototype.

Table 7. Temperature test extraction record

	A	B	C	D	E	F	G	H	I	J
Quietness	36.8	36.5	36.9	37.1	37.0	36.9	36.8	36.9	36.9	37.1
Exercising	37.2	37.1	37.3	37.2	37.4	37.5	37.2	37.4	37.3	37.6
After Exercise	37.7	37.4	37.8	37.9	37.9	38.1	37.7	37.9	37.8	38.2
Sleeping	37.1	36.7	37.2	37.3	37.2	37.0	37.1	37.2	37.0	37.3
	K	L	M	N	O	P	Q	R	S	T
Quietness	37.0	36.7	36.9	36.7	36.7	36.8	37.2	36.9	36.9	36.6
Exercising	37.2	37.0	37.1	37.1	36.9	37.1	37.4	37.3	37.5	36.9
After Exercise	37.8	37.7	37.6	37.9	37.6	37.8	37.9	37.8	38.1	37.5
Sleeping	37.2	36.9	37.3	36.9	37.0	37.1	37.3	37.2	37.4	36.8

4.1.2.2 Value and significance

The caregivers arrange the position of heat-sensitive sensor 3 as shown in Figure 31 which is under the armpit of infants. Then caregivers should open the receiving device and place it in the closed position of caregivers. When the temperature exceeds a set value range, the receiving device will give an alarm to remind the caregiver to do further processing. The prototype and patent certificate are shown in Figure 32.



Figure 32. The prototype and patent certificate

4.2 Case study 2, interactive clothing for couples

This case study was implemented from 2016 to 2017, and the project research carrier is interactive couple clothing.

4.2.1 Determining the categories of experiential prototype

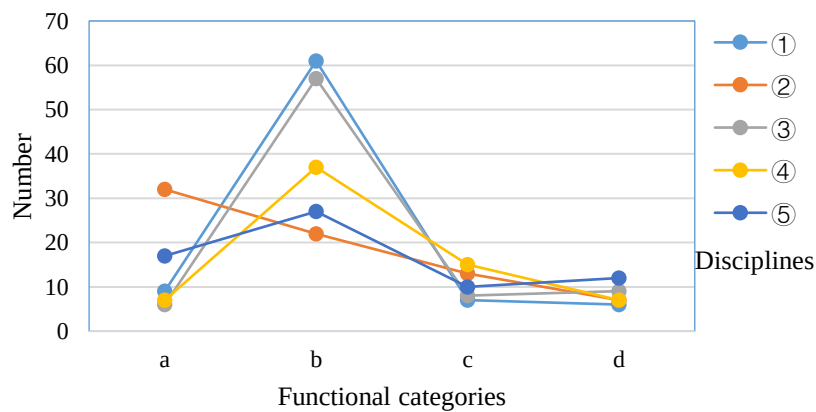


Figure 33. Survey data for prototype selection

Product design should combine with consideration of the future market demand. The future main target consumers of smart clothing are expected to be college students and other young people who are willing to accept new fashion things. In 2016, we conducted a questionnaire survey distributed to 369 students of two universities in Dalian China (Weizhen et al., 2017), participants were studying one of five disciplines (① artistic design, ② materials science, ③ literature, ④ management, or ⑤ information science), the demand rate for interactive clothing for couples was found to be more than 55%, which is significantly higher than the

demand for other types of clothing (see Figure 33).

Note that the survey participants were asked to select from the main functional categories of smart clothing: (a) medical-care clothing; (b) interactive clothing for couples; (c) sports monitoring clothing, and (d) nocturnal road-safety clothing. Based on the findings, option (b), i.e., interactive clothing, was selected as the categories of experimental prototype.

4.2.2 Purpose, methodology and findings

- The aim of this case study is to bridge the gap between human emotions and wearable technologies for interactive fashion innovation. To consider the reasons why smart clothing should satisfy the internet of things (IoT) technical functions and human emotional expression simultaneously, to investigate the manner in which artistic design perspectives and engineering methods combined effectively, to explore the R&D elements of future smart clothing based on IoT technology.
- This case study combines artistic design perspectives with information-sensing engineering methods as well as Kansei evaluation method. Micro-sensors and light-emitting diodes (LEDs) embedded in couples clothing prototype. The first experiment steps in the design and production of prototype clothing, and do the initial emotional evaluation. The second experiment is a comparative evaluation of the prototype and other typical smart clothing.
- The interactive clothing prototype was proven to correlate well with human emotional expressive patterns. The evaluation I indicated the prototype could stimulate the emotional response of the participants to achieve a higher score in the activate sensor state. Evaluation II revealed that in the process of interactive clothing design, the technical functionality should synchronize with the requirements of human emotional expression.

4.2.3 Hypotheses and methodology

4.2.3.1 Hypotheses

With the unremitting efforts of researchers, we have preliminarily realized the function of making the clothing smart. However, in the realization of technological progress, it is necessary to explore the possibility of integrating smart clothing into the daily life of consumers and the future development direction.

- *H1. Interactions may occur between two or more items of smart clothing.*
At present, the research of smart clothing mainly focuses on the use of clothing to reflect physiological data from the human body, and the majority of individual items of clothing

respond to a single person. However, the development of multiple pieces of clothing worn by different individuals and having a mutual reaction relationship should also be possible.

- *H2. Interactions between items of smart clothing can well match with the emotional relationship of the wearers.*

If multiple pieces of clothing are having a mutual reaction relationship exist, the primary emotional responses of the body can be reflected through this relationship. Smart clothing can reflect the relationship such as happiness, anger, sadness, and joy between wearers.

- *H3. As a new type of clothing, emotional interactive clothing can represent one of the main development directions in future daily smart clothing life.*

The future smart clothing lifestyle that people expect was predicted to occur in two distinct directions: performance-driven and fashion-driven (Lam Po Tang and Stylios, 2006). In the field of fashion design, aesthetic and emotional design performance is detached from the physical, social and spiritual attributes of clothing. The artistic aesthetics and human emotion characteristics that conform to the desired lifestyle of the target consumer group. Emotional interaction and transmission between people or between people and artifact may be more critical to smart clothing's success than its practical function elements.

4.2.3.2 Design methodology

The methodology employed in this study combines clothing style design, i.e., artistic design perspectives, with information-sensing engineering, i.e., engineering methods. This corresponds to the second design factor, "how," introduced above. Micro-sensor elements embedded in clothing and effective integration obtained, such that the clothing worn by two couples exhibits a mutual relationship, as expressed through a connected performance using light-emitting diodes (LEDs) or color effects. The reason for choosing LEDs and their color variations into design elements is that the visual effect of the LED is utilized. Because the three significant elements of clothing product design, that is, the style, color and material belonging to the visual category, and the LED illumination effect is noticeable.

4.2.4 Experimental approach

The experiment divided into two steps. The first step in the design and production of prototype clothing, and do the initial emotional evaluation. The second step is a comparative evaluation of the prototype and other typical smart clothing.

4.2.4.1 Prototype style and design basis

The prototype is interactive cold clothing for couples. The clothing items contain cold-proof liners with cotton filling, which can be freely replaced using differently colored materials,

suitable for a resource-limited society. Thus, one item of clothing can exhibit various colors, embodying the concept of energy-intensive design and providing a demonstration for realizing 5R (Reduce, Reevaluate, Reuse, Recycle, Rescue) design goal (Wang et al., 2014). The prototype design styles can see in Figure 34 (labeled a-d for future reference). Among them, “a” and “b” are two women’s styles, “c” and “d” is a couple of styles. The mainly pattern and size can see table 8 and Figure 35.



Figure 34. Clothing designs, labeled a-d

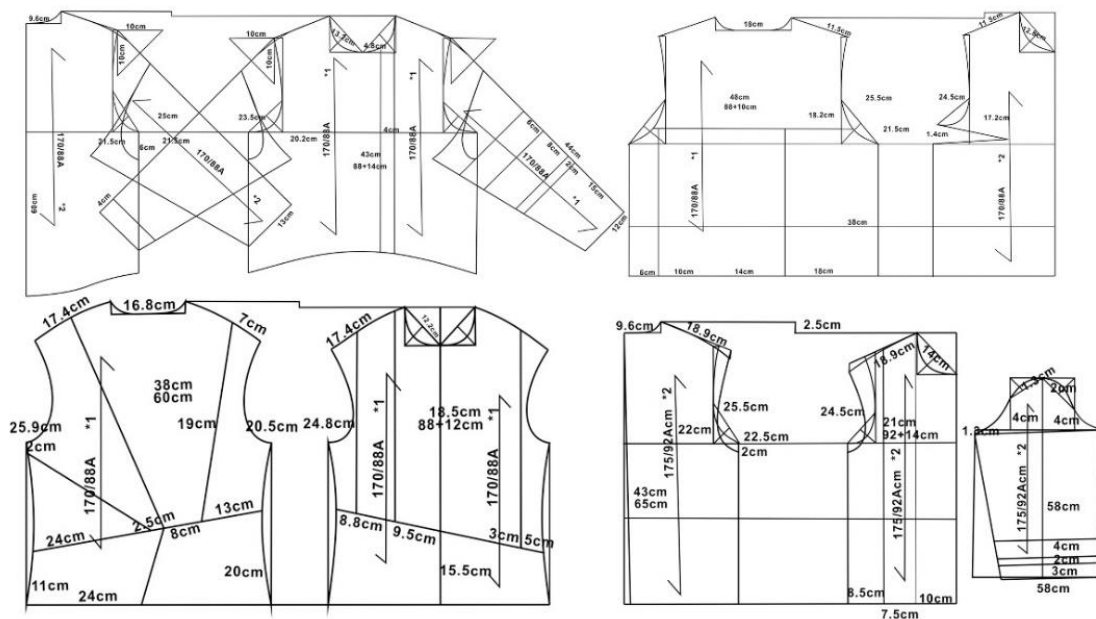


Figure 35. Pattern of style a-d

Notes: The sleeves of pattern b and c are ignored.

According to the conclusion of brain science(Pan et al., 2017; Marazziti et al., 2017), the romantic relationship between lovers is a typical representative of human emotions, so we selected lover couples (not for random people or co-workers) as prototype target user of interactive clothing design.

Table 8. Pattern size

Style & type Position	Style a 170/88	Style b 170/88	Style c 170/88	Style d 175/92
Bust	88+14	88+10	88+12	92+16
Front width	20.2	17.2	18.5	21
Back width	21.5	18.2	19	22
Armhole depth	21.5	21.5	20.5	22.5
Back neck drop	9.6	9	8.4	9.6
Front neck drop	13.2	12.8	12.2	14
Back length	61	48	60	65
Front length	43	48	60	65
Neck waist length	38	38	38	43
Sleeve length	44	57.5	45	58
Sleeve opening	25	24	29	29

From the psychological point of view (King-O’Riain, 2016), the distance can also represent the intimate or estranged relationship between two people. Therefore, we decided to use range as a trigger for the interaction, and embed the sensor into the clothing. To hide the sensing elements in clothing, we selected the relatively heavy winter clothes as a prototype design program.

In the external display design of the sensing reaction, the prototype is intended to draw on the more mature LED display technology (Chun and Lee, 2016; Rapisarda, 2016; Leonard, 2017).

4.2.4.2 Material selection

- **Clothing outer fabric and liner filler material**

The transparent material is the material of choice for research on technology in fashion design; therefore, the outer fabric of the prototype developed in this study was thermoplastic polyurethane. The liner filler material was a product known as “Wool Felt Poke Fun” in China, which is widely available in the fabric market and could be freely replaced using different material colors.

- **Sensor material**

The sensors were comprised of WH-335-DT and 5050-60RGB (Hongjing tech Co., Ltd., Shenzhen) LEDs in the form of a flexible flat ribbon that could be bent into any shape. Note that, using a special clip, these ribbons can be fixed in the shapes of various letters or patterns to meet different design requirements. The LED ribbons are quite small, and a unit can cut to contain only three diodes; thus, these LED ribbons can easily installed in very narrow parts of clothing. In this study, 5-8 LEDs embedded in every item of clothing.

A US100 (Telesky Electronic Co., Ltd., Shenzhen) ultrasonic sensor module was also used, which has a 5-m non-contact range function for both general-purpose input/output (GPIO) and serial communication. Considering the compatibility of traditional code programs and the operating speed, we also employed a STC12C5A60S2 (Hongjing tech Co., Ltd., Shenzhen) single-chip microcontroller. This microcontroller has ultra-high speed and low power consumption and is fully compatible with the traditional 8501 instruction code. A mic-transformer was also required, to regulate the operating voltage between the different modules. Note that the above electronic components are widely available in the electronics market and this design is, therefore, suitable for a resource-limited society.

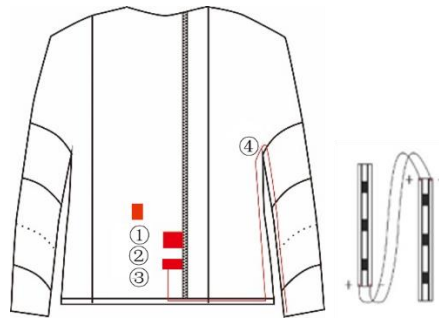


Figure 36. Electronic embedding design (style a)

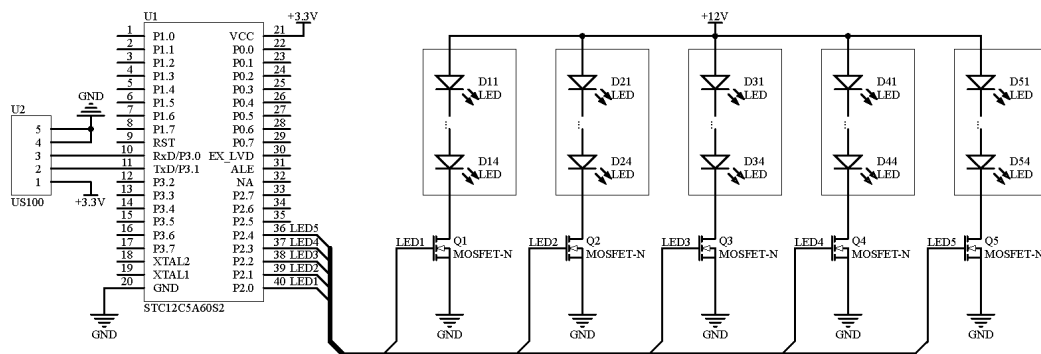


Figure 37. Schematic circuit design

• Electronic embedding design

Take style a as example, the battery ① and single-chip ② are hidden in the inside pocket, and sensors ③ embedded in the back center seam of the clothing, using insulated wire ④ hidden in the hem and side seams (Figure 36). Schematic circuit design which take 5 LEDs as the example can be seen in Figure 37. US100 as the main creative medium, and using single-chip programming process to control the LEDs brightness changes. The entire circuit access voltage is 12V, US100 operating voltage DC 2.4V - 5.5V, STC12C5A60S2 operating voltage is 3.3V, so the circuit also need to add a transformer. The above materials and the Kansei evaluation described below correspond to the “WHAT” design factor presented above.

4.2.5 Results

Realizing the interaction between two clothing items. The interactive clothing was proven to correlate well with human emotional expressive patterns (Figure 38). When the distance reduced between two individuals wearing the prototypes, the LEDs embedded in the two clothing items gradually illuminated. The illumination became apparent at a separation of 4.5 m, with full brightness being obtained when the wearers were separated by less than 1 m.

In Figure 38, style “a-1” is the effect of style “a” activated sensor, the difference between “a-1” and “a” is the LED effect in the right chest and left sleeve (shown in the red dotted circle). Style “b-1” is the effect of b-activated sensor; “b-2” is the effect of the dark environment (shown in the red dotted circle). Style “c” and “d” two items clothing together are couple style, and “d-1” is a close-up of the vertical bar-shaped LED effect in the front chest position.

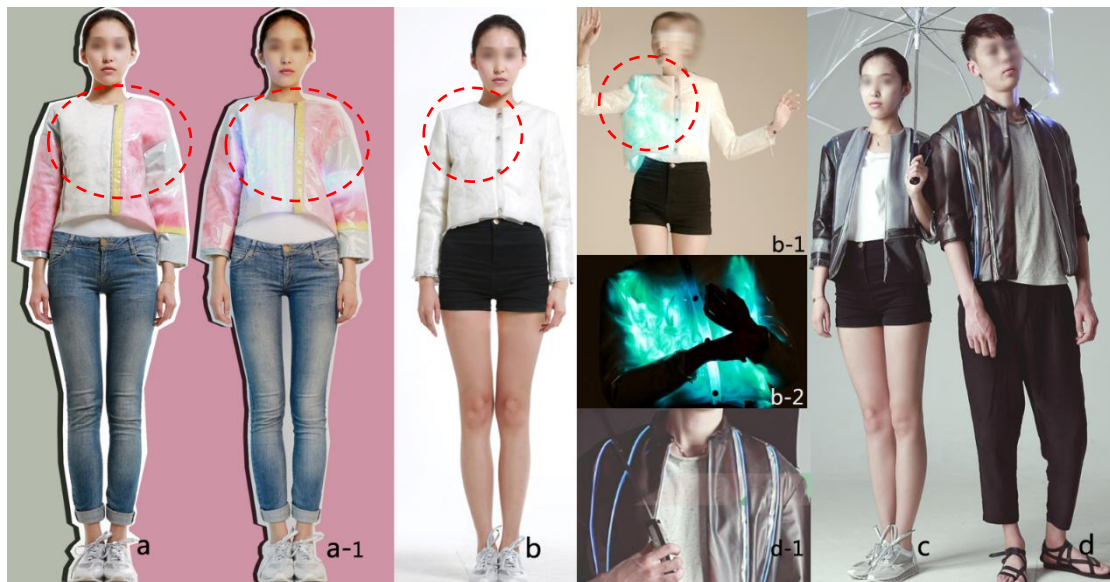


Figure 38. Photographs of prototypes visual effects

Notes: (left) Examples of style a, (center) style b, (right) styles c and d

4.3 Case study 3, interactive parent-child clothing

4.3.1 Purpose, methodology and findings

This case study was implemented from 2017 to 2018, and the project research carrier is interactive parent-child clothing.

- The aim of this case study is to bridge the gap from a transdisciplinary perspective between CPS architecture in the field of information science and emotional evaluation in the field of humanistic science for interactive fashion innovation, to explain how the transformation

could be realized from information to common feeling in the process of interactive clothing design.

- By using the CPCS architecture model in the hyper world, and takes the development process of interactive parent-child clothing as a case to analyze the transformation from the physical signal input to the social symbol recognition output, and verifies the feasibility of the CPCS model adopted in interactive clothing design.
- This case study provides a fruitful practical application reference for designers who are engaged in the art design field but not familiar with the relevant information technology and explains the application principle and technical process of CPCS for interactive clothing development.

4.3.2 Background and research question

The focus of Human Computer Interface (HCI) has moved looks to the future of technology and how it can enhance human activity and experience. As a multi-dimensional smart mechanism that tightly integrated computing, communication and control (3C) with a deep interaction between physical and cyber world, the cyber-physical systems (CPS) will provide HCI with the foundation of emerging and future smart services, and improve our quality of life in many areas (Duarte Filho et al., 2015; Huang et al., 2018; Barnaghi et al., 2015). Following the ascend anting application of CPS to the fashion industry, the academic and industry research concerns in this area across various disciplines stems have mainly been devoted to optimizing the interaction of smart clothing by the integration of information technology. Therefore, as a development branch of smart clothing and also one symbolic medium in the field of sociology (Kaiser, 1996), interactive clothing emphasizes the interactive characteristics of communication and expression between human and objects (Karrer et al., 2011; Wang et al., 2018b), and is adopted as the target carrier of this research project.

We are still confronted with several challenges from correlative information technology and humanities technology respectively:

- 1) Firstly, when we extend the functional definition of interactive clothing to provide interaction between different wearers or groups rather than just personal interaction with data, it is an important challenge to apply CPS in the development of interactive clothing. That is, how to meet the differentiated needs of different wearers and the differences in various attributes among each wear groups. In addition, most of the existing CPS architecture research is based on the logic framework of information science, but not the specific technical guidance for the non-information engineering personnel. Therefore, it is very important to optimize the CPS technical architecture which should with wide applicability for interactive clothing (Chen et al., 2016a; Alhafidh et al., 2017; Longo et al., 2017).

- 2) Secondly, current researchers seldom dabble in the systematic research of smart clothing from information modelling to humanistic evaluation, most of them analysed the information technology application or humanistic design from the single academic background (Trindade et al., 2016; Kim et al., 2016a; Salim et al., 2014; Weizhen et al., 2017), which may leads their inability to systematically explain the principle and process of how to extract data, transform and form humanistic feeling of the interactive clothing.

The aim of this case study is to bridge the gap between CPS in the field of information science and emotional evaluation in the field of humanistic science, to systematically explain how the transformation could be realized from information to knowledge in the process of interactive clothing design. By optimizing the CPS architecture of interactive clothing and conducting the Kansei Engineering (Nagamachi, 2011b) analysis of wearers' evaluation, to explore the R&D elements and suggest practical implication for interactive clothing design.

To attain the above objectives, this case study will answer one Major Research Question: What happened and how happened when the interactive clothing in the interactive transformation process from the information to knowledge stage? In addition, the Subsidiary Research Questions (SRQ) as follows. SRQ1: How is the connection could be realized between the signals in the field of information physics and the symbols in the various humanities and social dimensions? SRQ2: How is the humanistic evaluation could be realized the optimization in the stage of knowledge formation?

4.3.3 Prototype design following the CPCS model

Through the deduction analysis of the models in Figure 23, 24 and 25, we should realize that the R&D trend of the interactive clothing would move from the function of one piece of clothing to the interaction of multiple clothes approaching the CPS era. Next, the interactive clothing prototype is designed and demonstrated in accordance with the CPCS model.

As a symbolic concept clothing, the parent-child clothing is one perfect symbolic carrier of the emotional design of clothing, which can create a micro-hyper world to express the integration of family belonging and clothing culture, emphasizes parent-child interaction in everyday family life and family circle's emotional relations (Keel, 2016), sublimated into a spiritual category and cultural awareness (Brighouse & Swift, 2014). The interactive clothing conforms to the CPCS' technical conditions in which the interpersonal signal output interacts with the social symbol feedback of the family atmosphere. Therefore, we have reason to infer that the introduction of CPS into the design and development of parent-child clothing, and employ the concept of local area network to show the family atmosphere and spatial-temporal concept, will be an exciting and potentially promising research topic. Also provides a practical approach to realize the interactive clothing for the coming age of ubiquitous intelligent CPS applications.

4.3.3.1 The prototype development approach

Regarding style design, it takes the form of a three-piece family clothing combination of parents and children.

Concerning technical application, the sensing technology is used to create a family LAN system for three-piece clothing.

Regarding the appearance of the garment, the visual effect of the LED is utilized. Because the three significant elements of clothing product design, that is, the style, color and material belonging to the visual category, and the LED illumination effect is noticeable.

4.3.3.2 Design methods of interactivity

The first is the overall vision of the prototype design. The target wearers of the prototype are the family trio, namely the father, mother and child's three pieces of clothing for one parent-child clothing series, with the interactive effect that is transcending the traditional parent-child clothing.

Second, the appearance design of the prototype. Interactive clothing is a future trend, so the style of the clothing and the selection of the basic fabrics to be more avant-garde.

Finally, it is the technical design of the interaction between physical signals and social symbols. From a psychological point of view, physical space distance can represent a social symbol of intimacy or alienation of interpersonal relationships (King-O'Riain, 2016). Therefore, this study uses physical space distance as the signal trigger for interpersonal interaction. The spatial distance between these clothes was set as a physical signal of the interpersonal relationship, and the external appearance change of the clothing caused by the change of the spatial distance between these clothes is set as a social symbol which represents the change of the interpersonal relationship. Assuming that the three pieces of clothing will form a variety of interactions with one another, the specific design ideas, that is, the initial arrangement of time, task, and scheduling is as follows:

- When the distance between child and father two individuals wearing the prototypes was reduced, their clothing appearance produces a pattern of change at the same time.
- When the distance between the child and mother was reduced, their clothing produces a change simultaneously.
- When the child and parents were close to the set distance at the same time, three pieces of clothing simultaneously causing the change.
- When father and mother were closed, their clothing also causes a kind of change.
- Also, every piece of clothing has its own self-reaction.

4.3.3.3 Material selection

Selection of new fabrics

Regarding clothing fabric, the inner fabric is mainly selected DuPont Tyvek paper fabric and 3M luminous reflective fabric splicing. The new type of DuPont paper fabric is 100% high-density polyethylene. Visually, it is presented in the form of paper, two-way ventilated, and corrosion resistance. After complete combustion, the fabric is left with only water vapour and carbon dioxide, which does not damage the environment at all. The luminous reflective fabric could show different colours in the state of light and no light, which has changed the traditional visual concept of clothing. The outer fabric of clothing is TPU Transparent film, also known as thermoplastic polyurethane, is a class of burning furnace air pollution-free fabrics. The smooth and transparent texture could show the fashionable atmosphere of high technology and futuristic.

Selection of network components and LED strip material

Figure 39 is the pattern design of the three pieces of clothing, from left to right is the father's clothing, mother's clothing and children's clothing. Then take the mother's clothing as an example to illustrate the hardware embedded content.

To create a network with clothing as an interactive medium, the basic network components embedded in the clothing include power supplies, sensors, chips, and microprocessors. In terms of electronic components, each piece of clothing is independently using a battery (positioned in ① in Figure 39) and a microcontroller STC51 (Jiaxing Xinwei Electronic Technology Co., Ltd.) (positioned in ② in Figure 39) as the main control chip to control the sensor response, LED and the communication of three pieces of clothing. In the communication node, the ARM Cortex-M4 microprocessor was adopted as the primary control chip. For the sensor selection, the horizontal KC_IRS (Xinyujia Electronic Technology Co., Ltd.) (Positioned in ③ in Figure 39) was adopted as an infrared sensor module.

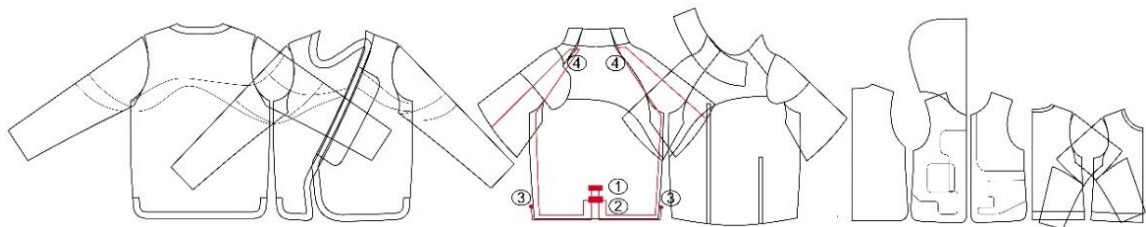
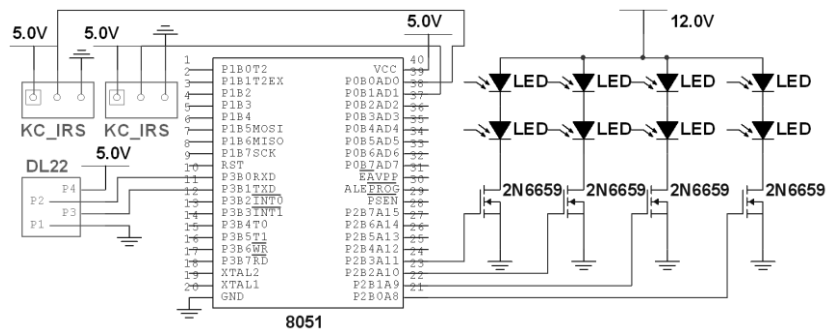


Figure 39. Pattern design and hardware embedding diagram



For the clothing-mediated manifestation of the social symbol output, two types of flexible light strips were selected to be embedded in the clothing. The LED using FPC as the base plate can be arbitrarily curved flexible flat strip with a 5050-60GRB model (Shanghai Jingzheng Lighting lamp Co., Ltd.) (positioned in ④ in Figure 39), can be fixed to a variety of letters or patterns of shape. The EL cold light strip, with characteristics of repeatedly being folded and curved, low power consumption, and can achieve steady-slow, flash-fast and flash three kinds of effects, suitable for use in clothing design. The circuit design is shown in Figure 40.

4.3.3.4 Prototyping



Figure 41. Photos of prototypes

The design and production details of this series of prototypes are shown in Figure 41. These prototypes' reflective fabric material and white, orange, black three colours combination embody the sense of science and technology due to their strong visual contrast and brightness contrast. The colours and style of the three-piece clothing are echoed, full of interest and relevance. Mother's wear with different colour stitching with a large area of white, stable and no lack of lively, trumpet sleeves style enhanced stereoscopic and layered sense. Children's wear is an orange hooded vest with a white sweater, it has a rhythm effect, and elbow's zipper segmentation enhances the profile of the fashion sense. The strong colour contrast between the left side and right side of the father's wear enhances the visual impact; the exaggerated curve of the overlap gives a fashionable atmosphere.

- *Four types of interaction performances*

Note the special effects that are indicated by the white dotted circle in Figure 42.

When the distance between child and father decreases within 2.5 meters, the two garments produce a reaction respectively. The performance form is the front of the children's wear LED thin-line strips and the father's clothing horizontal LEDs strips at the same time start shiny (Fig. 42-a).

When father and mother stand together within 2.5 meters, the heart-shaped LEDs pattern on the chest of father's clothing and the LEDs pattern of mother's shoulder shimmy simultaneously (Fig. 42-b).

When the distance between the child and the mother decreases within 2.5 meters, the two garments produce a reaction respectively. The manifestation is that the LED strips embedded in the hem of their garments start to shine at the same time (Fig. 42-c).

When the child and parents are close to the set distance within 2.5 meters at the same time, the sleeves of the three wears shine simultaneously produce a change (Fig. 42-d).



Figure 42. Interactive effects of prototypes

- *Three types of self-interaction performances*

Mother's clothing, the embedded LEDs is activated when the collar buckled up, to achieve the expected interactive effect (Fig. 42-e).

Children's clothing, the reaction is through the Kcirs infrared sensor to the reaction of the hat, causing the front pocket decorative LED activated, to achieve the expected interactive effect (Fig. 42-f).

Father's clothing, its own reaction is triggered by the induction of the photosensitive diode module, causing the front of the zipper part of the LED strips activated, to achieve the previous envisaged interactive effect (Fig. 42-g).

According to the above, various demonstration effects of these prototypes, embedding CPS could greatly enrich the design concept and manifestation of the parent-child clothing. This series of clothing achieved the interaction of individuals and groups as mentioned in the social level of the CPCS model, realizes the representation of the social symbol from the physical distance signal recognition to the parent-child relationship. This simple transformation process from data to information and knowledge illustrates the application forms of CPS in the process of interactive clothing design and development which response to the aim of this case study, MRQ and SRQ 1 mentioned above.

4.4 Case summary

In this chapter, through the development of the infant's smart clothing prototypes in case study 1, the idea of the feasibility of IoT sensing applied to clothe is verified. The application effect of prototypes and the acquisition of national patents show that IoT technology can be applied to our daily clothing life, which lays a practical foundation of interactive clothing development for the follow-up study of the project.

Through the prototyping of interactive couple clothing in case study 2, the interactive reactions between two pieces of clothing were realized. Satisfactory prototyping results, validating the hypothesis that the development of multiple items of clothing worn by different individuals and having a mutual reaction relationship. By triggering design, interactive clothing can reflect some interpersonal and emotional relationship, such as happiness, anger, sadness, and joy between wearers. The satisfactory effect of the prototype also illustrates the reasons why smart clothing should satisfy the IoT technical functions and human emotional expression simultaneously, and it also prompts us to investigate the manner in which artistic design perspectives and engineering methods combined effectively, to explore the R&D elements of future smart clothing based on IoT technology.

In case study 3, the diversified interaction results achieved through a three-piece set of parent-child clothing. The prototype development process successfully grafted the CPS architecture in the field of information science and art design in the field of humanistic science

from an interdisciplinary perspective for interactive fashion innovation, enriching the expression form of social symbol semantics of clothing. By using the CPCS architecture model in the hyper world, and takes the development process of interactive parent-child clothing as a case, to analyze the transformation from the physical signal input to the social symbol recognition output. Four types of interactive performances and three types of self-interaction performances have verified the feasibility of the CPCS model adopted in interactive clothing design.

Chapter 5

Emotional Evaluation, Data Analysis, and Discussion

Because case study 1 is only intended to verify the feasibility of IoT technology applied to clothe function development, no further data analysis and evaluation has been done. Case studies 2 and 3 used Kansei engineering methods for data extraction and evaluation respectively.

5.1 Case study 2, Data analysis and evaluation on interactive couple clothing

5.1.1 Kansei evaluation I

We used the semantic differential (SD) method to analyze the effects of the interactive clothing on the psychological responses of wearers. That is, the participants are required to analyze the smart clothing as wearers. Several emotion models exist. For example, Larsen and Diener (1992) have developed a model divided into eight categories (a-h), which can be applied to both active and inactive smart clothing: a, arousal; b, excitement; c, joy; d, fun; e, composure; f, laziness; g, sadness; h, anger. We employed this eight-way split model as an evaluation reference to consider the relationship between the emotions of the wearers and the clothing worn by various couples. Each emotion was quantified as a value within the range of 1-10, using fuzzy inference.

We conducted an emotional survey evaluation experiment under activating and inactivate range sensors conditions for the LED sensors embedded in each couple's clothes. Considering the future main target consumers of smart clothing are expected to be college students and other young people, 34 boy and girl college couples participated in this wearing experiments. 16 of them in the laboratory light in a darker environment wearing experience, with a time of about 30 minutes; 18 people in the outdoor night environment, and the experience of wearing for about 60 minutes.

Each group of participants was boy and girl with a couple of relationships. We require each

pair of wearers in the course of the experiment as much as possible in the daily life of the behavior to act, and to complete the basic process of two people approaching from more than 5 meters and then gradually pulling away.

The form of filling out questionnaires after wearing experience was adopted. The experiment divided into two steps: The first group of tests, each pair of couples in the clothing without activating the sensor case of wearing experience and fill out the emotional value test questionnaire. The second group of tests, each couple's wearing experience is carried out in the case of sensors activating and then rate the emotion scale.

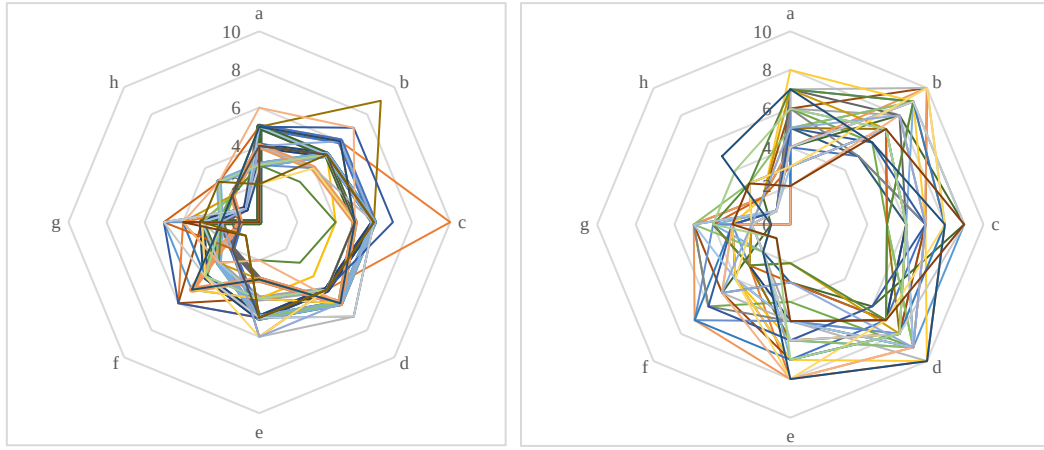


Figure 43. Results of Kansei evaluation on emotional expression for non-interactive and interactive, for eight-way split model.

Notes: a, arousal; b, excitement; c, joy; d, fun; e, composure; f, laziness; g, sadness; h, anger.

	a	b	C	d	E	f	g	h
Non-interactive	4.00	5.26	5.59	5.47	4.47	3.50	2.91	1.29
Interactive	5.09	7.82	6.85	8.29	5.62	3.94	3.35	1.50

Notes: Average emotion values for interactive and non-interactive, for eight-way split model.

The survey data for the active and non-interactive clothing differed significantly. In the case of the inactivate scale for the LED sensor, eight-way split model Figure 43-1 shows that the main range of the evaluation index fluctuation is within 6. However, for the activate range of the LED sensor, Figure 43-2 shows that the range of the evaluation index fluctuates obviously, with many of the evaluation values reaching the maximum of 10. The average emotion values for the interactive and non-interactive are shown in Table 9. The paired samples t-test revealed that $P=0.008 \leq 0.05$. From the results of this Kansei evaluation, it can stimulate the emotional response of the participants to achieve a higher score in the activate sensor state; therefore, H1 and H2 mentioned in Chapter 4 are validated.

5.1.2 Kansei evaluation II

After completing the emotional value evaluation, follow-up comparative evaluation experiment by observation method is continued. That is, the participants are required to analyze and judge the differences between various types of smart clothing as bystanders.

1) Experimental form

Multi-category smart clothing comparative evaluation by observation method. For the corresponding clothing pictures and video using the observation evaluation method. The evaluation score is a scale comprised of seven ranks on a questionnaire sheet. Participants responded to each adjective scale by marking the rating after watching the specified smart clothing videos and pictures.

2) Evaluation subject

The college students who have participated in previous experiments. Including design disciplinary (as the designer cluster), information engineering disciplinary (as engineer cluster) and other disciplines (as consumer cluster) of the three clusters, each of 6 people. Because smart clothing design involves the integration of art design and information sensing technology, as well as the need for non-professionals to the comprehensive evaluation of the consumer's identity, the three clusters of participants, are selected for comparative evaluation. These participants had participated in the first experiment, and a return visit was inviting them to participate in the second experiment was conducive to the continuity of the experiment.

3) Evaluation object

Prototype (Figure 44-1), ANREALAGE (2), smart sportswear (3, De Acutis and De Rossi, 2017), healthcare clothing (4, Chen et al., 2017).

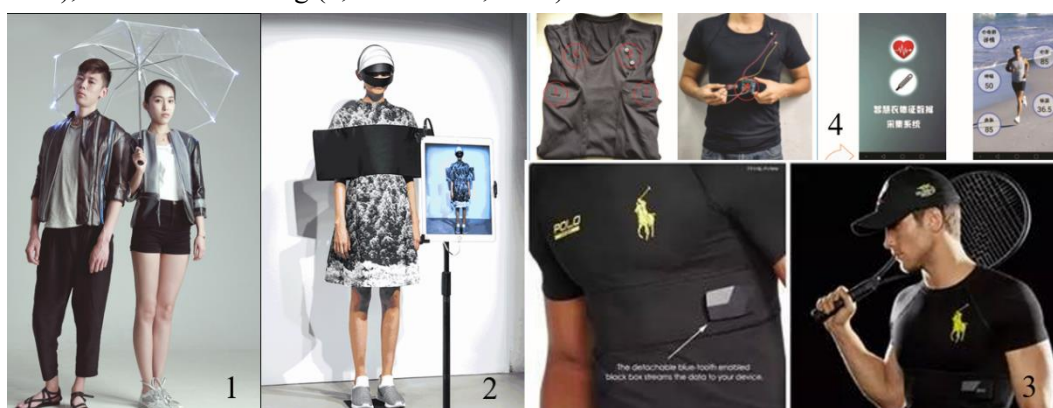


Figure 44. Evaluation object

Annotation of compare objects:

- The ANREALAGE (Figure 44-2) is a Japanese fashion brand. Its designer, 森永邦彦, is known as the “Revolutionary of the Digital Age”, specializing in the combination of clothing and technology, he has endless innovation and fantasies about

fabrics.

Source of the Video playback URL:

<https://www.youtube.com/watch?v=7eaaN5ACQUM&feature=youtu.be>

- Ralph Lauren OMsignal Polo Tech shirt is a typical smart sportswear(Figure 44-3). It is the first luxury sports lifestyle brand offer smart apparel collection and tested at the 2014 US Open. This shirt uses biometric technology to collect athlete's physiological signals including heartbeat and respiration as well as some psychometrics.

Video playback URL: <https://www.forbes.com/sites/hunteratkins/2015/09/08/ralph-laurens-futuristic-fashion-the-polotech-smart-shirt/#24999f4f59a5>

- Wearable 2.0 healthcare system(Figure 44-4), which consists of sensors, electrodes, and wires, is the critical component to collect users' physiological data and receive the analysis results of users' health status provided by cloud-based intelligence.

4) Evaluation words.

By referring to the “Human aspects in smart clothing were dealt with usability, functionality, durability, safety, comfort, and fashion” proposed by Cho, et al., (2009), and the consumer needs of functionality, expressiveness, and aesthetics (FEA) raised by Hwang et al., (2016), the evaluation vocabulary was identified as: functional, practical, futuristic, emotional transmission, appearance style, interactive technology.

5) Evaluation scales: take item “functional” as example, we divided “functional” into semantic differential scales with seven points from the lowest level 1 of “functional” to the highest level 7.

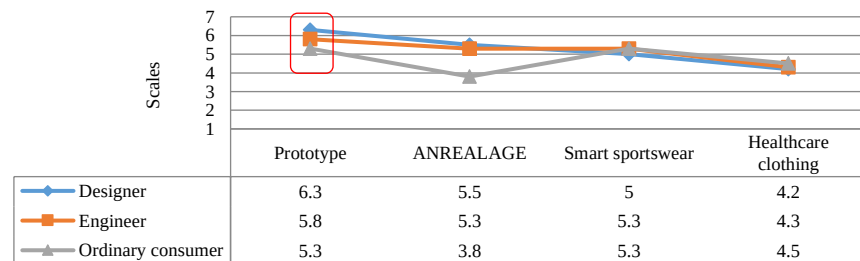


Figure 45. Comparison of average values by designer, information engineer and consumer clusters

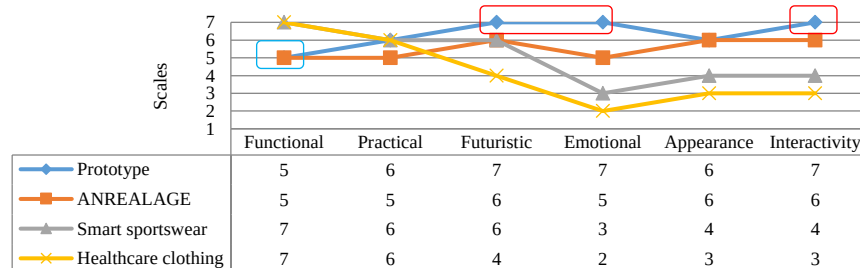


Figure 46. The evaluation value of designer cluster to four kinds of smart clothing

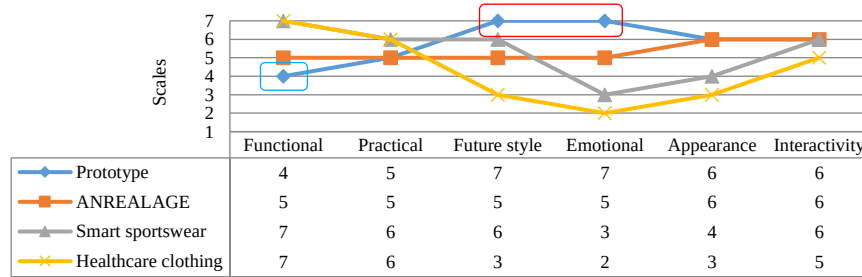


Figure 47. The evaluation value of information engineer cluster to four kinds of smart clothing

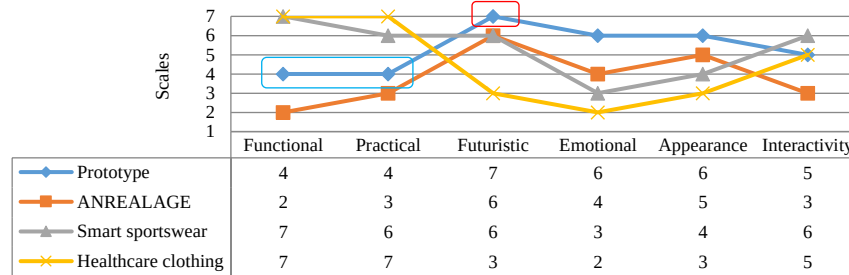


Figure 48. The evaluation value of ordinary consumer cluster to four kinds of smart clothing

Overall, Figure 45 shows that the average score of the prototype is significantly higher than other three types of smart clothing in the three clusters' evaluation of these four types of smart clothing. Since the evaluation of the prototype is the highest, then it is necessary for us to extract three clusters to analyze the details of the prototype evaluation separately.

Figure 46 uncovered designer cluster think the best point of the prototype is future-style, emotional and interactive; the most vulnerable is functional. Figure 47 reveals the engineers' view that the prototype's best point are future-style and emotional, the weakest point being functional. Figure 48 shows that consumer cluster thinks the best point of the prototype is future-style, the most vulnerable are functional and practical.

Comprehensive evaluation of different groups, people's expectations of the future of smart clothing is not just focused on the use of high-tech. The three clusters have the highest degree of satisfaction with the futuristic and emotional elements of the prototype; therefore, the idea proposed by H3 that the emotional interaction is the main direction of future smart clothing development is established.

However, the functional satisfaction of the three clusters to the prototype is not higher, which indicating that the balance between the application of high-tech and emotional interaction in the product design process need to improve. We can see that the design concept of implanting wearable technology in clothing to improve the function of garments is not yet a widespread resonance among consumers. Only by implantable smart technology to effectively improve the products more in line with the needs of emotional communication, more in line with the expected lifestyle, these are the most important indicators for people to decide whether

to wear smart clothes. This is the key content of future smart clothing design, but also the “WHAT” element mentioned above.

5.1.3 Case discussion

Human-centered and emotion-based design for “WHAT” element and H3 mentioned above. It is necessary to provide clothing with vitality rather than, simply, embedded IoT technology, if the clothing is to express the wearer’s emotions vividly. Although this is a difficult task, deep-thinking designers to identify future subjects should use the socially innovative design perspective (Nagai, 2015). Thus, it is crucial for forward-thinking designers to embrace this challenge.

The design process for interactive clothing should be human-centered, rather than focusing on technology. Interpersonal communication is the focus of social existence and for useful technology must support socialization (Tao, 2005). Nelson and Stolterman (2012) offered a formulation of design culture’s fundamental ideas, in the design process applied to an infinite variety of design domains. Further, Giacomini (2014) has stated that the model of human-centered design is based on a pyramid hierarchy, in which interactive, sociological considerations and the metaphysical meaning contact with the design. Because clothing has a metaphysical attribute, Baurley (2004) has proposed that people can interact with the clothing of others nearby by changing the visual appearance. In the design process, Schütte (2005) and Lee *et al.* (2002) contributed to the balance between functional technology and emotional expressiveness.

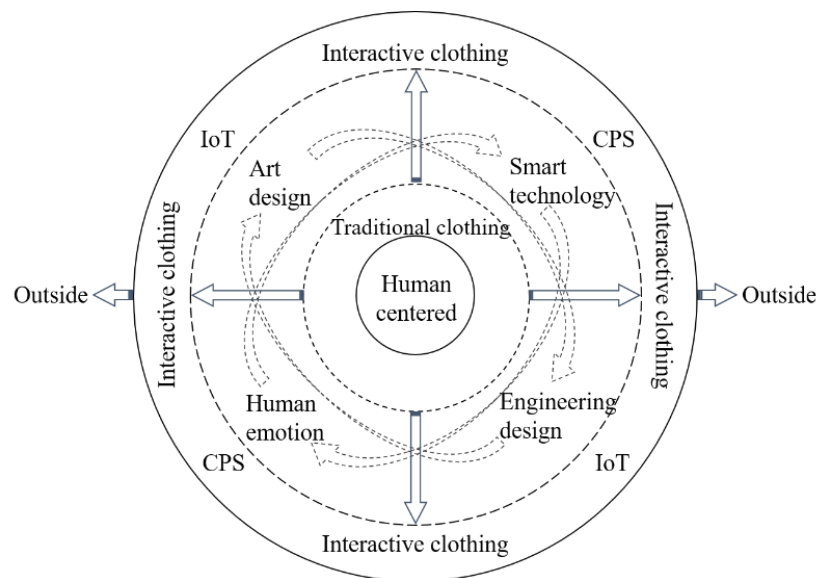


Figure 49. Human-centered R&D process for interactive clothing

The human-centered approach cannot neglect consideration of human emotions. For product design, traditional cognitive approaches have tended to underestimate the user

emotions which acts as a critical component of artifact sense-making (Rafaeli, and Vilnai-Yavetz, 2003; Spillers, 2004). Wensveen (2002) have designed a mood alarm clock that illustrates the importance of a tight coupling between the emotional level of interaction, and the actual use of such interactive technology.

As shown in Figure 49, we should further investigate the structure of the emotions underlying human clothing-related behavior, obtain a more inclusive vision of the social psychology of smart clothing. Interactive clothing must satisfy both technical functionality and human emotional expression requirements (Bakker and Niemantsverdriet, 2016). In other words, both basic and advanced social properties of clothing must be incorporated. These also correspond to the third design factor “WHAT” and H3 introduced above.

5.1.4 Limitations and further research

The sensors combined with LED display technologies is a relatively mature technology, the use of this technology in prototype design simply for the convenience and easiness to achieve an interactive effect, so the project team did not develop special sensing technology. The interactive effects and comfort (wearability) of the prototype should be further improved if specialized, advanced, washable, durable, and flexible sensing elements or smart fabrics are developed in the future. During the experiment, the participants' wearing experience time is limited, and the evaluation is mainly subjective. The evaluation participants are all college students, so the evaluation results may not be universally representative.

In the next research, we will focus on the hierarchy and typology of smart clothing R&D based on humanities and technology perspective simultaneously, especially focus on the new concept of IoC which we have pioneered proposed.

5.1.5 Case conclusion

In this case study, interactive clothing for couples was examined using experimental prototypes. The efficacy of this clothing was then assessed using a Kansei evaluation. Hence, it was found that the prototypes satisfied the criteria of stage 2.0 of the smart clothing (Figure 15) and the interactive clothing evolutionary roadmap (Figure 23).

For interactive fashion designers, design for the future IoC, rather than focusing on purely functional behavioral or aesthetic-appeal criteria, emphasis should be placed on blending technological developments in engineering with emotional responses in product design, on identifying artifacts that trigger and mediate emotional responses, and on seeking the emotional structure underlying human clothing-related behavior.

Artistic design perspectives should be effectively combined with engineering methods

during the R&D of interactive fashion products. The primary task of design thinking is to achieve the external aesthetic form without excessive consideration of the technical characteristics of the product. In contrast, the engineering approach aims to realize technological applications without emphasizing the added value or social attributes of the product. An effective designer should embrace the opportunities and challenges of achieving smart clothing evolution from stage 1.0 to 3.0. Such a designer should exhibit both artistic creativity and engineering rigor, integrating design and engineering perspectives, and blending emotional responses with smart technology to achieve interactive fashion innovations.

5.2 Case study 3, Data analysis and evaluation on interactive parent-child clothing

According to the CPCS model, in the process of interactive clothing design, the formation of wisdom needs to reach the cognition level through knowledge mining, i.e., humane evaluation. Because this case study uses parent-child clothing that emphasizes emotion as research carrier, so the evaluation approach adopts the Kansei engineering method rather than ergonomic or functional evaluation methods. By comparing the prototype with the ordinary parent-child clothing, the advantages and disadvantages of the prototype design are analyzed, and the groundwork for the subsequent configuration technology flow is laid.

5.2.1 Selection of comparative evaluation objects

Evaluation elements include Casual style, Formal style, Graffiti style, Deconstruction style, National style and our prototype, i.e., optical sensing Interactive style (Fig. 50).

These six categories could cover and represent the existing types of parent-child clothing on the market as follows.

a) Casual style

This style of clothing refers to people wearing in an unrestrained and free leisure life, emphasizing a relaxed and straightforward style.

According to Wikipedia, casual style wear is a western dress code category that comprises anything not traditionally appropriate with more formal dress codes: formal wear, semi-formal wear, or informal wear. In general, casual wear is associated with emphasizing personal comfort and individuality over formality or conformity. As such, it may be referred to as leisurewear. In a broader sense, the word “casual” may be defined as anything relaxed, occasional, spontaneous, “suited for everyday use”, or “informal” in the sense of “not formal” (although notably informal attire actually traditionally refers to a Western

dress code more formal than casual attire, a step below semi-formal attire). Source: https://en.wikipedia.org/wiki/Casual_wear



Figure 50. Photos of comparative categories

b) Formal style

The design of this style clothing is concise, elegant and dignified. It highlights the texture of the fabric and the fine cutting and shows a classical beauty.

According to Wikipedia, formal wear *is the traditional Western dress code category applicable for the most formal occasions, such as weddings, christenings, confirmations, funerals, Easter and Christmas traditions, in addition to certain audiences, balls, and horse racing events. Generally permitted other alternatives are the most formal versions of ceremonial dresses (including court dresses, diplomatic uniforms and academic dresses), full dress uniforms, religious clothing, and most rarely frock coats. In addition, formal attire may be instructed to be worn with official orders and medals.* Source: https://en.wikipedia.org/wiki/Formal_wear

c) Graffiti style

This style refers to the various patterns of clothing contrast strong, color blending. An extraordinary, exaggerated or casual style depicts the graphic, text or color in an abstract sense.

d) Deconstructive style

This style emphasizes the concept of unstructured design. It uses the concept of decomposition, emphasizing breaking, superimposing, reorganizing, attaching importance to the individual or the component itself, and opposing the overall unification to create fragmentation and uncertainty feeling.

e) Interactive style

This style refers to smart clothing that developed using Cyber-Physical Systems /Internet of Things technology. The distance, sound, movement between the pluralities of clothes (dressers) can automatically adjust the appearance, colour, model of the clothing, and the smart interactive reaction is formed between many pieces of clothing.

f) National style

This style refers to the clothing that combines the elements of traditional national costumes, combined with the needs of modern life, social and other occasions, with both national elements and modern fashion design elements. This costume shows the ultimate symbol of national culture, and its design elements include, for example, Japanese kimonos, Mexican jeans, Middle Eastern keffiyeh, Scottish kilts, and so on.

5.2.2 Selection of semantic opposite adjective

Table 10. Semantic opposite adjective pairs

Category I: Style design level			Category II: Technology content level			Category III: Extended meaning level		
No	Positive	Negative	No	Positive	Negative	No	Positive	Negative
1	Avant-garde	Conservative	10	Smart	Rigid	19	Affinity	Alienated
2	Staid	Lively	11	Environmental	Destructive	20	Warm	Cold
3	Exquisite	Rough	12	Flexible	Bound	21	Interesting	Stodgy
4	Childlike	Mature	13	Technology	Traditional	22	Surprise	Disappointed
5	Creative	Monotonous	14	Interactive	Isolated	23	Relaxed	Gloomy
6	Elegant	Vulgar	15	Open	Restricted	24	Enthusiastic	Indifferent
7	Fashionable	Outdated	16	Systematic	Messy			
8	Cross-border	Closed	17	Multifunctional	Single			
9	Concise	Tedious	18	Emotional	Rational			

Three categories of words, total 24 pairs of antonym phrases were constructed, respectively choice from the three-level concept of parent-child clothing, which was summarized by the

prior interview: the clothing style design, engineering technology, parent-child clothing extension meaning (Table 10).

5.2.3 Participants' selection and evaluation methods

Clothing industry personnel, information science or optoelectronics engineering personnel, and children's parents. The reasons for choosing these three groups as participants are as follows: Clothing industry personnel, specially engaged in clothing design professionals, could compare clothing to make a professional evaluation. Because the prototype of this experiment used information sensing technology and optoelectronic technology, therefore, it is hoped that the researchers of information engineering and optoelectronic engineering could give the corresponding evaluation from the perspective of the application of intelligent technology. The target purchase group of parent-child clothing is the parents' cluster so that the result will be more convincing with the help of the target users' evaluation.

The participants, including 14 people engaged in the clothing industry (6 male, 8 female; 7 participants is 18-29 years old, 1 participant is 30-39 years old, 6 participants is 40-49 years old), 23 photoelectric information technicians (11 male, 12 female; 16 participants is 18-29 years old, 5 participants is 30-39 years old, 1 participant is more than 40-49 years old, 1 participant is 50 years old) and 36 children's parents (7 male, 29 female; 1 participant is 18-29 years old, 30 participants is 30-39 years old, 5 participant is more than 40-49 years old).

The Questionnaire can see in the Appendix section. In particular, it should be emphasized that the questionnaire in the clothing evaluation link style 1 to style 6 of the question is the same 24 questions, in order to ensure the credibility of the results of the questionnaire feedback, we randomly disrupted the sequencing of these questions.

After providing brief introductions to participants about the different contexts of the six categories evaluate elements, we ask participants according to their knowledge background and living habits to rate each of perceptions regarding these six categories parent-child clothes used semantic differential scales by observation method. For the evaluation scales, take pair item "Smart and Rigid" as an example (Table. 11), we divided into 7 points from the "very smart" level to the "very rigid" level. Finally, 73 valid questionnaires were collected.

Table 11. Example of an SD scale with seven points for adjective pair *smart/rigid*

Very smart	Quite smart	Slightly smart	Neutral	Slightly rigid	Quite rigid	Very rigid
3	2	1	0	-1	-2	-3

Before statistical data, we first tested the rationality of the selection of participants in this differentiated group with the stacked column chart. According to the questionnaire scoring statistics of designers, engineers and parents, we can find that the peak values of the designer cluster are between 60 and 80 (Figure 51), the peak of the engineering cluster is between 100

and 120 (Figure 52), and the peak of the parent cluster is between 160 and 180 (Figure 53). Due to the significant differences in cluster evaluation scores, the selection of participants using this differentiated cluster could provide a guarantee of the credibility of the evaluation



Figure 51. Evaluation value of 14 designers

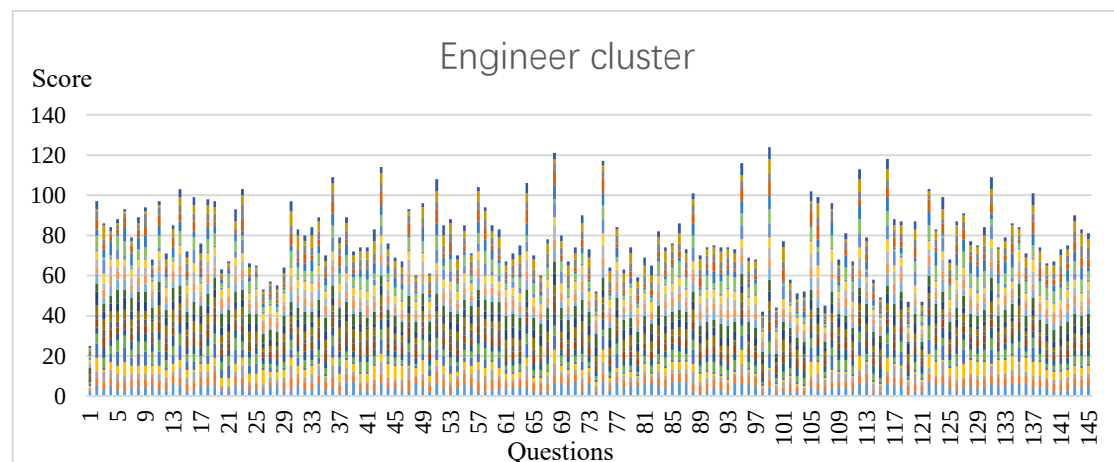


Figure 52. Evaluation value of 23 engineers

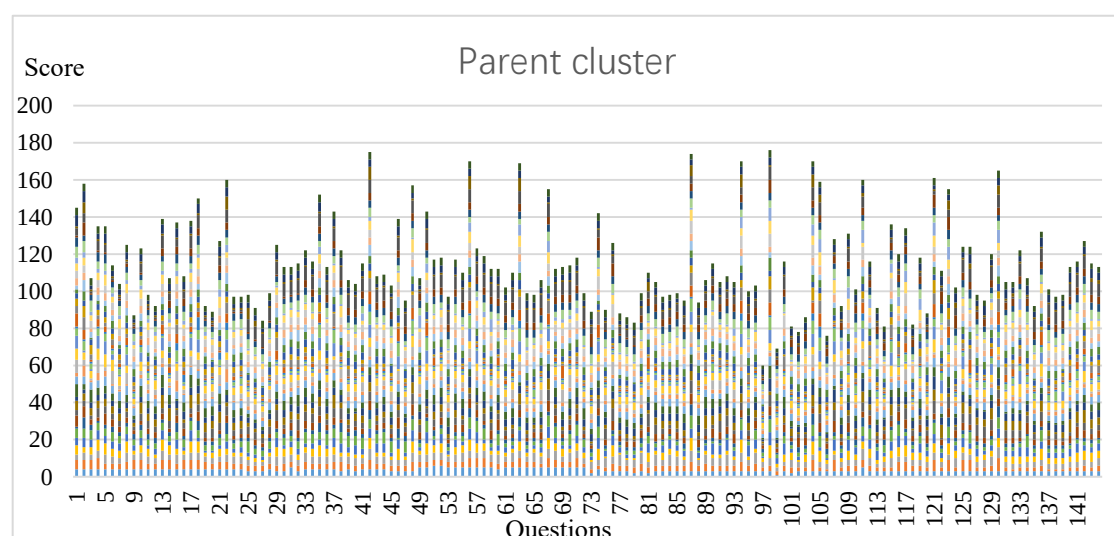


Figure 53. Evaluation value of 36 parents

5.2.4 Differences between the two categories of parent-child clothing

According to the scale statistics on the average value of the evaluation, the comparison between the prototype and the other five categories of traditional parent-child clothing is made to excavate the difference between the interactive and the traditional parent-child clothing.

According to the 73 participants' choice of "desire to buy" in all six categories of parent-child clothing, the highest ranking is the prototype, i.e. Optical sensing sci-fi style (accounting for 32.9%), followed by the Dress style (26%) which is also the highest ranking among the five categories traditional parent-child clothing. Therefore, we chose the Dress style as an object compared to the prototype.

Table 12. Results of the paired-samples T-test

		Mean	SD	SE	<i>t</i>	<i>P</i>
Rigid	Smart	1.781	1.557	.182	9.774	.000
Monotonous	Creative	.890	1.663	.195	4.575	.000
Outdated	Fashionable	.027	1.624	.190	.144	.886
Closed	Cross-border	1.411	1.373	.161	8.782	.000
Vulgar	Elegant	-1.027	1.972	.231	-4.452	.000
Tedious	Concise	-1.466	2.109	.247	-5.939	.000
Destructive	Environmental	.178	1.743	.204	<u>.873</u>	.386
Bound	Flexible	1.068	1.719	.201	<u>5.312</u>	.000
Traditional	Technology	1.781	1.669	.195	9.118	.000
Isolated	Interactive	1.192	1.560	.183	6.526	.000
Open	Restricted	-.137	2.057	.241	<u>-.569</u>	.571
Messy	Systematic	-1.082	2.228	.261	-4.149	.000
Single	Multifunctional	1.808	1.912	.224	8.079	.000
Rational	Emotional	-.616	2.271	.266	<u>-2.319</u>	.023
Alienated	Affinity	.219	1.652	.193	<u>1.134</u>	.261
Cold	Warm	-.603	1.614	.189	-3.191	.002
Stodgy	Interesting	-.096	1.108	.130	<u>-.740</u>	.462
Disappointed	Surprise	.164	1.871	.219	<u>.751</u>	.455
Gloomy	Relaxed	-.192	1.883	.220	<u>-.870</u>	.387
Indifferent	Enthusiastic	.521	1.519	.178	<u>2.927</u>	.005
Conservative	Avant-garde	.630	1.568	.184	<u>3.434</u>	.001
Lively	Staid	-.397	2.559	.300	<u>-1.326</u>	.189
Rough	Exquisite	-.753	1.949	.228	-3.302	.001
Mature	Childlike	.630	2.010	.235	2.678	.009

According to the results of paired-samples t-test between prototype and traditional parent-child clothing (see Table 12), 16 of the 24 constructs have significant fixed effects with a p-value lower than 0.05. The creativity and other indicators of the prototype are significantly higher than that of the traditional parent-child clothing. However, the disadvantages of the

prototype are just the emotional extension elements. There is the most significant difference between the bold and underlined parts of the *t*-value in Table 12. The constructs corresponding to these values, especially the Concise, Elegant, Systematic, Exquisite and Warm options, are the weakest point of the prototype, but also the key area for future development that needs to be improved. The Smart, Technology, Cross-border, Multifunctional, and Interactive can represent the advantages and characteristics of the prototype.

Table 13. Top five value in prototype and traditional parent-child clothing

Style design level			Technology content level			Extended meaning level		
Constructs	Proto-type	Tradi-tional	Constructs	Proto-type	Tradi-tional	Constructs	Proto-type	Tradi-tional
Avant-garde	39.7	19.2	Smart	45.2 (2)	1.4	Affinity	21.9	16.4
Staid	5.5	13.7	Environmental	24.7	12.3	Warm	21.9	20.5 (4)
Exquisite	17.8	23.3 (3)	Flexible	34.2	13.7	Interesting	23.3	16.4
Childlike	13.7	9.6	Technology	45.2 (3)	1.4	Surprise	17.8	12.3
Creative	43.8 (4)	12.3	Interactive	34.2	5.5	Relaxed	15.1	15.1
Elegant	11	24.7 (2)	Open	17.8	5.5	Enthusiastic	24.7	19.2 (5)
Fashionable	23.3	30.1 (1)	Systematic	4.1	12.3			
Cross-border	47.9 (1)	8.2	Multifunctional	39.7 (5)	8.2			
Concise	5.5	11	Emotional	21.9	15.1			

To ensure the rationality of the analysis, we continued the frequency statistics method. We separately extracted the five semantic adjective items with the highest frequency value of the above-mentioned two categories of clothing evaluation as the index of differential analysis (Table. 13). These five indicators are also the characteristics and advantages of the two categories of parent-child clothing respectively. According to the value of the frequency statistic scale, the highest score of the prototype is Cross-border (47.9%), Smart (45.2%), Technology (45.2%), Creative (43.8%) and Multifunctional (39.7%). While the advantage of the Dress style clothing is Fashionable (30.1%), Elegant (24.7%), Exquisite (23.3%), Warm (20.5%) and Enthusiastic (19.2%), they are also the key improvement factors of future interactive parent-child clothing development.

Just as Apple CEO Tim Cook delivered MIT's 2017 commencement speech: technology should marry with the liberal arts and humanities that makes our hearts sing. Researchers should take the human body as a critical frontier for creating powering and deeply engaging ways of interacting with computers (Broadhurst, & Price, 2017). For clothing that embodies people's feelings, embedding CPS can easily achieve interpersonal interaction effect. Nevertheless, the results from our evaluation experiment show that technology-oriented clothing is relatively ruthless and lacks humanistic emotion. Therefore, how to enhance the emotional value of smart parent-child clothing should be one of our next research goals.

5.2.5 Limitations and follow-up studies

In the application of information technology, the prototype developed in this case study is limited to the category of interactive manifestation and does not involve the scope of the big data measure and algorithm analysis of CPS (Kindness et al., 2017). For the challenges mentioned in the introduction of this case study, that is, the differential needs of different objects, we need to deepen the research of machine learning and optimize the algorithm of merging time, task, and scheduling. The mining and categorization of the basic physical signals and physiological signals of the wearer, as well as the recognition and classification of the social symbols that can be displayed by the clothing, will help to improve the functional development and expand the application of the interactive clothing.

In the context of product design and evaluation, the limitations of the comparative method of image observation and evaluation may lead to the deviation of the experimental result from the real situation. Clothing is a kind of product that not only pays attention to the visual feeling but also needs to wear experience. The interactive parent-child clothing emphasizes the interactive experience. Of all those who took part in the survey, only 2 were from Japan and the remaining 71 were from China. Since participants were too concentrated in a single country, the data in this survey had some limitations. Therefore, the follow-up study will adopt the evaluation method of participants' wearing experience test, and participants from different countries should be invited to participate in the experiment.

5.2.6 Case conclusion

This case study summarizes the relationship between CPS architecture and interactive clothing design from a transdisciplinary perspective and takes the development process of interactive parent-child clothing as a case to verify the feasibility of the CPCS model for interactive clothing design.

This case study provides a fruitful practical application reference for non-information engineers, especially for clothing designers who are engaged in the art design field but not familiar with the relevant information science and technology, and explains the application principle and technical process of CPCS in the process of interactive clothing development. The satisfactory results of the design and evaluation of prototypes demonstrate that the potential of HCI combined with CPS for developing interactive clothing has just begun to be tapped, and there are more technical methods and opportunities than ever before to create compelling everyday dress experiences and deep personalization for fashion pioneers.

5.3 Summary

Through three progressive prototyping, evaluation, analysis and discussion, the feasibility of the CPCS model has been verified.

In the case study 2 for couple clothing, the evaluation I indicated the prototype can stimulate the emotional response of the participants to achieve a higher score in the activate sensor state, therefore, the emotional interaction and transmission between people or between people and artifact may be more critical to smart clothing's success than its practical function elements. The evaluation II revealed that in the process of interactive clothing design, the technical functionality should synchronize with the requirements of human emotional expression. Therefore, we proposed that the interactive fashion designers should design for the future IoC, rather than focusing on purely functional behavioral or aesthetic-appeal criteria, emphasis should be placed on blending technological developments in engineering with emotional responses in clothing design, on identifying artifacts that trigger and mediate emotional responses, and on seeking the emotional structure underlying human clothing-related behavior. Artistic design perspectives should be effectively combined with engineering methods during the R&D of interactive fashion products.

In the case study 3 for parent-child clothing, the evaluation results clarify the advantages and disadvantages of interactive clothing, and also bring enlightenment to the social semantic interaction symbol and form excavation of interactive clothing.

Based on the scale statistics on the average value of the evaluation from clothing industry personnel, information science or optoelectronics engineering personnel, and children's parents, the comparison between the prototype and the other five categories of traditional parent-child clothing is made to excavate the difference between the interactive and the traditional parent-child clothing. The score with significant differences illustrates that the emergence of successive waves of CPS can enable new symbolic interactive ways of coupling the clothes to different wearers. Besides, according to the value of statistic scale, the advantage of the prototype is Cross-border, Smart, Technology, Creative and Multifunctional, while the disadvantage is Concise, Elegant, Exquisite, Warm and Enthusiastic which are the critical improvement factors of interactive parent-child clothing development. From interactive representation, it is necessary to meet the differentiated needs of different types of wearer individuals or groups because of the interaction among different wearer individuals or groups, as well as the differences in various issues and attributes among each wearer or group. Different types of feedback forms are represented by different clothing external symbols. Various communication symbols that can express social message to be output during the interaction of different individuals or groups.

Chapter 6

Knowledge Transfer and Enlightenment to Interactive Clothing Design

6.1 Knowledge Transfer

Up to this point, the knowledge structure of interactive clothing has preliminarily formed. According to the principle of Socialization-Externalization-Combination-Internalization (SECI) model (Nonaka & Takeuchi, 1995/1996) which has become the cornerstone of knowledge creation and transfer theory, in the first four stages of this study, the tacit knowledge and explicit knowledge related to interactive clothing were explored respectively, and the related knowledge system was formed preliminarily.

As shown in Figure 54, this research adopts the five-phase SECI model of the knowledge-creation process to architecture the knowledge structure in five phases: (1) sharing tacit knowledge; (2) creating concepts; (3) justifying concepts by prototyping; (4) evaluating prototype; (5) cross-leveling knowledge.

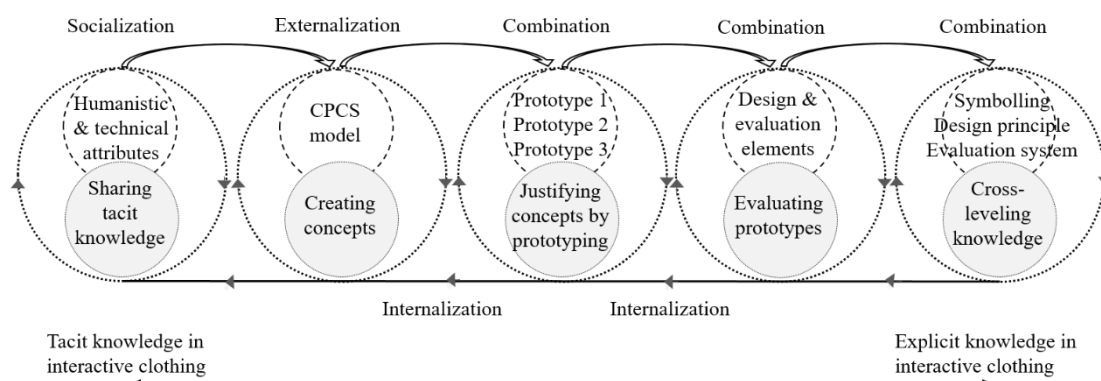


Figure 54. Knowledge transfer of this research (after Nonaka & Takeuchi, 1995)

- Phase 1: Sharing tacit knowledge

In the stage of literature theory analysis, i.e., the socialization of knowledge, this research obtains tacit knowledge 1, i.e., the humanistic attributes of interactive clothing, through the integration of needs psychology, clothing sociology and clothing design hierarchy analysis. By comparing the IoT data evolution theory, CPS architecture and interactive clothing development technology, tacit knowledge 2, i.e., the technical attributes of interactive clothing, is acquired.

- **Phase 2: Creating concepts**
Corresponds to externalization, the conceptual model of the technological process of interactive clothing is summarized based on the tacit knowledge 1 and 2 acquired in Phase 1, and the explicit knowledge 1, namely CPCS model, is acquired.
- **Phase 3, 4: Justifying concepts by prototyping and evaluation**
New concept created in the previous step need to be justified at some point in the procedure. Three types of clothing prototypes, including smart infant clothing, interactive couple clothing, and parent-child clothing, successfully validated the feasibility of explicit knowledge 1, i.e., the CPCS model, and formed a new explicit knowledge 2, i.e., the prototype design and development methods. Through the evaluation of the prototype, re-mining tacit knowledge 3, i.e., the design optimization elements and evaluation elements.
- **Phase 5: Cross-leveling knowledge**
This is the process by which this study transforms explicit concepts into knowledge systems during the combination of knowledge. Three essential explicit knowledge including interactive clothing signal and symbol conversion, design principles, and design evaluation framework. As a result, the tacit knowledge gradually transforms to form the explicit knowledge of interactive clothing. And this explicit knowledge may trigger a new round of interactive clothing innovation or the exploration of tacit knowledge responses to internalization.

6.2 Completion of loops steps in the CPCS model

The process of the above humanistic evaluation is also an extensive process of knowledge mining in the CPCS model. The conclusion of humanistic evaluation is the cognition of interactive clothing design optimization, which is also the summary of wisdom. Wisdom further guiding the optimized setting and measurement of configuration basis signals, thus forming the complete nine loops steps of interactive clothing CPS. These are responses to the SQ2 presented in the introduction section.

The experiment progressed to this step, the technical process of the entire CPCS architecture with parent-child clothing as a case was fully implemented.

- 1) Potential applications of such models

In the development process of the interactive clothing, step ⑨ is to perform the following two steps according to the evaluation result of the previous step. The first is to improve the social symbolic performance of clothing in interpersonal interactions, for example, the diversified message transmitted by special changes such as styles and colors exhibited by clothing can generate more social communication symbols (Devendorf et al., 2016; Kan et al., 2015). Secondly, the microprocessor embedded at the physical level is configured an improved task to guide the optimized form of the signal setting, such as the mining of the brain wave or other human body's physiological and even psychological signals (Kosti et al., 2018).

2) Summarize the symbolization of the signal

The experimental results demonstrate that the CPCS framework has a universal guiding significance for various types of interactive clothing development, which solves the problem that the CPS architecture of interactive clothing should have wide applicability mentioned above in Chapter 1. In addition, the CPCS model takes the correlation analysis of CPS architecture and DIKW level as the icebreaking and provides systematic research and development roadmap for the development of interactive clothing, which also can responses to the existing dilemma mentioned above in Chapter 1.

For the SRQ 2 of this research to be answered, the development process from information to knowledge is the evolution from the data of information science to the wisdom of humanistic science, that is, the process of symbolization widely recognized by social groups. As shown in Figure 55, the four components split into information science behaviour (data, signal) for technical conversion steps and the humanistic science behaviour (wisdom, symbol) for humanistic cognition steps, they constitute the basic structure of information transformation into knowledge.

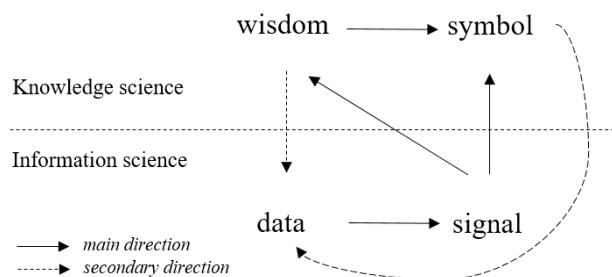


Figure 55. The symbolization of the signal

- When the data extracted from the clothing or the wearer's body are converted into a digital signal, it can be transformed into a wisdom content that is accepted by people, such as the experience, and this experience will also feedback and change the developer's settings for the data probe of clothing.

6.3 The “C” design principle for interactive clothing

Academic research on the design process and development elements of smart clothing is still inadequate. In the limited literature, relatively complete research focuses on the model summarized by Lee (2016), that is, Cradle-to-Cradle Design Framework (Figure 57) which is an integrated framework focused on sustainable design and evaluation processes of smart clothing design. This model integrates many theories respectively: McDonough & Braungart (2002) introduced the Cradle-to-Cradle Design Model, Lamb & Kallal (1992) proposed the Functional-Expressive-Aesthetic Consumer Needs Model, Kelly (2016) described the WEearable Acceptability Range Scale, and Ajzen (1991) revealed the Theory of Planned Behavior. However, it can be found from the architecture level that this model only focuses on the human perspective of the target users in the design process from attitudes toward the behavior, and there are no specific indicators in the application level of information technology in fashion design. Therefore, the model cannot be called a design system, and there is no complete structure level and design index. So, what are the design criteria or principles of interactive clothing?

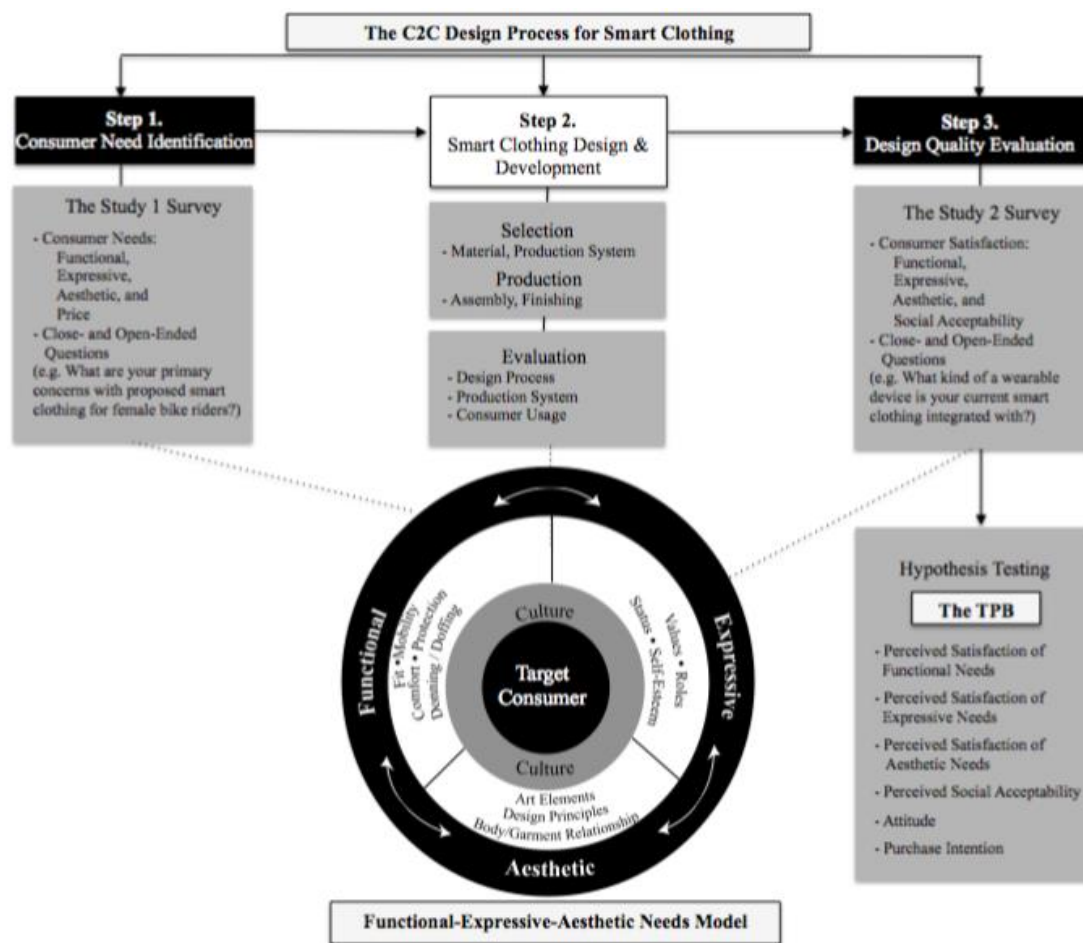


Figure 57. The cradle-to-cradle design process for smart clothing (Lee, 2016, after McDonough & Braungart (2002), Lamb & Kallal (1992) Kelly (2016) and Ajzen (1991))

By summarizing the implementation process of the prototype experiments in case studies 2 and 3, 18 design principles of interactive clothing with letter “C” as the first letter can be distilled. We divided the interactive clothing design architectures into three factors as levels, links and contents are shown in Table 14. These elements response to the SRQ 3 mentioned in Chapter 1 of this research.

Table 14. The “C” principles and architecture of interactive clothing design

No.	Levels	Links	Contents
1	Essential	Subject aspects	(1) Clothing; (2) Consumer-centered; and (3) Culture symbol.
2	Technical	Information engineering aspects	(4) CPCS; (5) Connection; (6) Conversion; (7) Computing; (8) Communication; (9) Control; (10) Cognition; and (11) Configuration.
3	Humanistic	Art design aspects	(12) Critical thinking; (13) Creativity.
4	Objective	Realization form aspects	(14) Communication; (15) Convenience; (16) Characterize; and (17) Captivating symbol
5	Organizational	Personnel aspects	(18) Collaboration

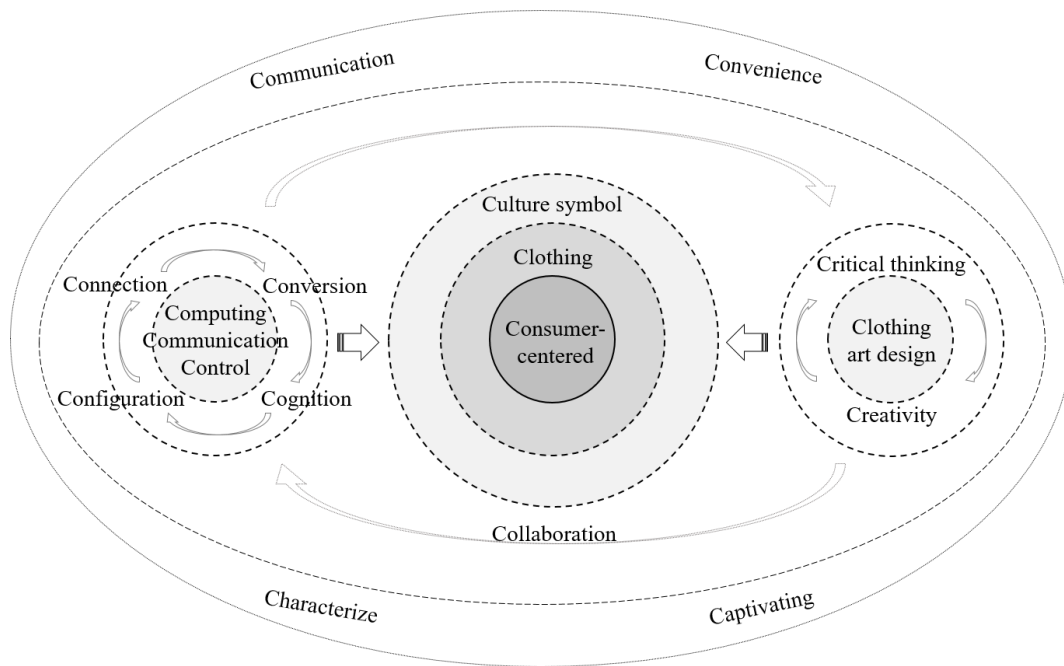


Figure 58. The logical relationship of “C” principle for interactive clothing design

The logical relationship between them is shown in Figure 58. With the dressers and the potential cultural semantic representation of clothing (Figure 58, Center) as the core, the art design team of interactive clothing (on the right side of Figure 58) and the information engineering development team (on the left side of Figure 58) are respectively formed and engaged in interactive collaboration. As a new thing, the art design of interactive clothing should adopt critical thinking to get creative (Figure 58, right), and the realization of its interaction effect cannot be separated from the application and development of CPS technology in the field of

information engineering (Figure 58, left). The purpose of the final realization of interactive clothing, the effect of rendering, the distinctive characteristics and attractiveness to the user (Figure 58, peripherals), is to achieve the new form of communication with clothing as the medium and to provide convenience for life, to enrich its characteristics, and to attract the desire to acquire interactive clothing. The meaning of each “C” principle is as follows:

1) Consumer-Centered

The target consumer (intended wearer) is at the core of the model. The development of interactive clothing should be human-centered and take people’s social communication as the foundation. Clothing should serve the communicative needs of people, not the people to serve to clothe.

Interactive clothing should be able to meet the wearers’ psychological needs of Esteem and Self-Actualization level. It should be consistent with the meaning of the high level in the model of Figure 11.

2) Clothing

The essence of interactive clothing is still clothing. It is a kind of clothing with a technical function attached, not a mere smart device, let alone a machine. Advanced interactive clothing should be consistent with the meaning of the high level in the model of Figure 22.

3) Culture symbol semantic

In the symbolic semantic expression of clothing, interactive clothing should meet the standards of social functions such as conveying certain social and cultural connotations and facilitating communication and expression. It needs to be aligned with the meaning of the high level in the model of Figure 12.

4) Critical thinking

For the design of innovative interactive clothing that upsets the concept of traditional clothing, its inspiration needs critical thinking. Regarding design categories to reach the level of designer custom-made, while also emphasizing creativity, originality and high added value, embodying the characteristics of pop and fashion to provide customized design services for niche customers. It should be consistent with the meaning of the high level in the model of Figure 14.

5) Communication

The function of interactive clothing is to realize the two-way interaction between the human body and clothing, wearers and their environment. Move closer to the level of the IoC concerning functionality. It needs to be aligned with the meaning of the high level in the model of Figure 17.

6) Convenience

The purpose of interactive clothing is to provide convenient services for the interpersonal communication of the dressing person in daily life. Converge to service in DIKWS to achieve that data as a service, information as a service, knowledge as a service, and wisdom as a service on the whole (Figure 19).

7) CPCS

Under the CPCS framework, the technical means of information processing are optimized the computing, communication and control algorithms, to realize the data cycle processes from the connection, conversion to cognition and configuration (Figure 27).

8) Collaboration

Cross-domain team-working research and development. During the three prototyping process, the development team members were drawn from the fields of Information Engineering, Optoelectronic Science, Garment Engineering and Fashion Design respectively. According to the results of those prototype development test, it is also necessary to introduce a professional team of Textile Engineering to realize the research and development of smart textiles.

9) Characterize

Embodying the characteristics of high-level bidirectional interaction. Two interactive clothing case prototypes only use distance sensing to drive the appearance of clothing changes in the form, and increasingly iterative artificial intelligence technology can enrich the form of clothing interaction. In the aspect of signal input, the existing mature technology such as blood pressure pulse sensing, brain wave sensing and other technical forms can be applied to interactive clothing development. Regarding symbol output, the symbolic semantics of interactive communication can be diversified to form richer features. It should be consistent with the meaning of the model Figure 55.

10) Creativity

Creative design and aesthetic value. The development of smart clothing has completed the technology-centered of the most basic technology reserve stage. Interactive clothing development should be divorced from the limitations of engineering technology development and enhance creativity from the perspective of “taking Art and Humanities as the center.”

11) Captivating

The ultimate effect of clothing should be attractive and can arouse the desire to own it.

6.4 The framework of the evaluation criteria for interactive clothing design

6.4.1 Background and significance

The evaluation system refers to an organic whole with internal structure, which is composed of multiple indicators representing the characteristics of evaluation objects in various criteria and interrelated elements. Up to now, although some scholars put forward individual evaluation methods for case studies, the academic evaluation system of smart clothing has not been

established, and interactive clothing as a new type of smart clothing cannot expect the existence of targeted evaluation system.

This research has summarized in the CPCS model that the current design evaluation direction for smart clothing or interactive clothing are mainly divided into three dimensions, that is effective indicators (emotion, five senses, etc.), ergonomics indicators (action, posture, comfortable, etc.), and functional indicators (sport monitoring, healthcare, entertainment, etc.). But in the specific case study, this research only adopts the evaluation method of Kansei Engineering, and cannot systematically evaluate the effect of the prototype.

Based on the above academic situation and summary of the case implementation experience in this research, in order to fill the academic gap, this research proposes to build the basic structure of interactive clothing design evaluation system from the framework level.

In addition, the purpose of establishing the hierarchical structure of the evaluation system is not merely to evaluate the ranking and advantages and disadvantages of clothing works, but also to guide the improvement of the evaluation system of interactive clothing in the future, and to encourage the object of evaluation to develop in the right direction and objectives.

6.4.2 The structure of the evaluation criteria

6.4.2.1 Theoretical basis and method

When designing the evaluation criteria system, we should first have the scientific theory as the guidance. So that the evaluation criteria system can be rigorous and reasonable in the basic concept and logical structure, grasp the essence of the evaluation object and be targeted.

According to “Evolutionary route based on psychology, sociology and design” (Figure 24) and “Evolutionary route based on IoT and CPS applications” (Figure 25), the two models summarized the characteristics and attributes of interactive clothing in psychology, sociology and design from the humanistic point of view, and summarized various characteristics and attributes of IoT and CPS applications from the technical point of view. Moreover, the evolution and development of interactive clothing should not be lower than the fourth layer attribute or function in the model, and we use these characteristics and attributes as the main reference standard for the design and evaluation architecture of interactive clothing.

The method of designing the evaluation criteria system adopts the Analytic Hierarchy Process (AHP), which is decomposed into sub-indicators by the total index and then decomposed into sub-indicators by the sub-index. Usually, people call these three levels as the target level, the criterion level, and the indicator level. As a reference, we divide the hierarchy of interactive clothing evaluation system into five levels: Target level, Perspective level,

Criterion level, Index level, and Element level.

6.4.2.2 The frame structure of the evaluation criteria

According to the AHP method, the frame structure can be divided five levels according to the following ideas (Table 15). These elements also response to the SRQ 3 mentioned in Chapter 1 of this research. The relationship between this five-layer structures can be found in model Figure 59.

Table 15. AHP of the interactive clothing evaluation system

Level	Purpose	Meaning	Content
Level 1	Evaluation objectives	Target level	Interactive clothing
Level 2	Evaluation perspective	Perspective level	Humanistic & technical
Level 3	Evaluation form	Criterion level	Subjective & objective evaluation
Level 4	Evaluation guidelines	Index level	Emotion & aesthetics; function, ergonomics & emerging technologies
Level 5	Evaluation factor	Element level	Cognition, perception, associational, Communication, Esteem, Self-actualization, Expressive, Interactivity, Communicative, Auxiliary, Comfort, Temperature, Pressure, Action Posture; Textile Science, Sensing, communication, response control, Deep learning, ... <i>N</i> element

- Level 1 structure: evaluation objectives, that is, interactive clothing
- Level 2 structure: evaluation perspective. Take interactive clothing as the main body, with humanistic and technical perspective as the wings.
- Level 3 structure: evaluation form and criteria. Subjective evaluation and objective evaluation.
- Level 4 structure: evaluation guidelines and index. Subjective indexes are emotion and aesthetics, and the objective index includes function, ergonomics and the application of emerging technologies, etc.
- Level 5 structure: evaluation factors.

Among them, Emotion index includes expressive, Desire to own, communication, esteem, self-actualization and other elements.

Aesthetics index includes cognition (formal), perception (sensory), associational (meaning and values), etc. Among them, cognition (formal) factor mainly for clothing styles and colours, which in turn involves the formal beauty of clothing design factors, such as contrast, symmetry, scale, rhythm, and emphasis elements.

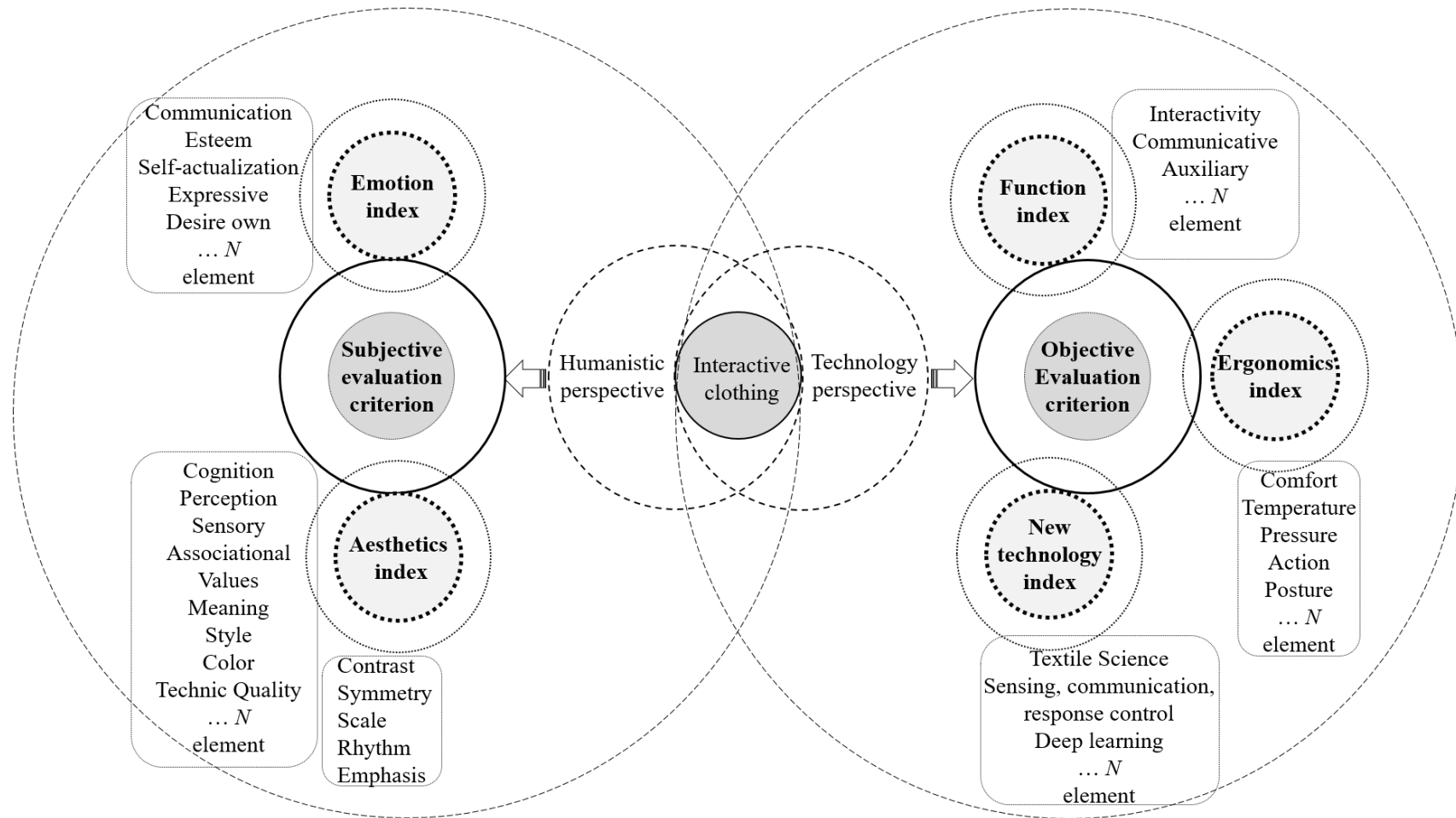


Figure 59. The structural relationship of evaluation criteria for interactive clothing design

Function index includes interactivity, communicative, auxiliary and other elements.

Ergonomics index includes Comfort, temperature, pressure, action, posture, and other elements.

The new technology index, including textile science, sensing, communication, response control, deep learning, and other elements.

Chapter 7

Conclusion

The main differences between the contents of this study and previous studies by other scholars are as follows: (1) This study pioneered a new field of smart clothing research, namely interactive clothing; (2) This study introduces CPS technology into clothing development from the perspective of art design; (3) A research framework for interactive clothing was initially established.

The interactive clothing, a topic on which there is little previous research, an evolutionary branch of smart clothing in the field of information science, which emphasizes the function of social symbols that mutual interaction or communication between the wearer and their environment based on the integration of information science and traditional clothing. Combining CPCS with clothing engineering design to input a certain physical signal into clothing, the interactive clothing can output a specific social symbol that people or clothing environment can perceive and generate corresponding interaction. This kind of social symbol is the expression form of the interactive clothing as the interactive medium for people to interact with the environment.

With the gradual integration of IoT/CPS into people's daily life and the growing development of smart textile technology, the revolutionary evolution has been occurring at an unprecedented rate in the fields of clothing; interactive clothing will play an increasingly important role in future interpersonal communication and interaction.

The research on interactive clothing should integrate the two opposing perspectives of humanities and technology, and bridge the gap between humanities and technology from an interdisciplinary perspective in the process of developing and evaluating the prototype of interactive clothing. Because in essence, interactive clothing is still clothing, and the interactivity is an additional feature. No matter how complex and changeable the interaction is in technology, it should not be divorced from the material and social attributes of clothing as well as the material and spiritual functions of clothing.

7.1 Contribution

7.1.1 Main practical contribution of the study

7.1.1.1 The contribution of prototyping practice

An overview of the whole practice process of this research, the implementation of the prototype experiment began in 2012 and achieved progressive results in three stages. These prototypes were developed from easy-to-difficult design processes and interdisciplinary research methods provide a fruitful practical application reference for designers who are engaged in the art design field but not familiar with the relevant information technology.

- The first stage was in 2013, two types of infant's smart clothing were developed. Analyze the feasibility of the application of IoT technology in the design and development of garment products from the perspective of sensor technology application. The purpose of the two prototyping experiments is to combine IoT sensing technology and infants clothing design, to develop a real-time monitoring alarm clothing for infants. As a result, two of China's utility model patents have been granted, which illustrates the feasibility and rationality of the original planning of this research. Furthermore, the fundamental study of interactive clothing has established the technical foundation by these experiments.
- The second stage is which interactive clothing for couples has been made from 2016 to 2017. It is preliminary study for IoC. The aim is to bridge the gap between human emotions and wearable technologies for interactive fashion innovation, to consider the reasons why smart clothing should satisfy the IoT technical functions and human emotional expression simultaneously, to investigate the manner in which artistic design perspectives and engineering methods combined effectively.
- The prototype development of interactive parent-child clothing is the third stage from 2017. The aim is to bridge the gap between CPCS architecture model and emotional evaluation, to explain how the transformation could be realized from information to common feeling, to refine the design elements for interactive clothing.
- At the stage of the following two prototyping experiments, in the aspect of practical research, we focus on the existing problems and research motives mentioned in Chapter 1, two series of interactive clothing prototypes were successfully designed and produced, and Kansei evaluation experiments and data analysis were carried out. And the theoretical research focuses on the research aims and objectives mentioned in section 1.3 of Chapter 1, defines the definition of interactive clothing, and build many innovative theoretical models that can verify each other with the prototype from the perspective of humanities

and technology as well as their integration.

7.1.1.2 Contribution to the clothing industry and the aging society

This topic expands the industry chain of the clothing industry, not only integrating the main elements of traditional clothing industry but also adding CPS/IoT technology, which makes clothing and clothing, clothing and environment, clothing and people interact. More importantly, it puts forward the concept of the internet of clothes (IoC), that is, the industrial prospect of interaction between people in social groups through clothing medium.

At the application level, this topic focuses on the social needs of the next 10-20 years, especially the interactive clothing needs of the aging society is of great significance. With the continuous development of the information society, Smart Home, Smart City, and intelligent transportation will bring more convenience to our lives. At the same time, in the face of the elderly's living needs, emotional needs, communication needs, interactive clothing will become a vital carrier medium in the future.

7.1.2 Original contribution to knowledge science

7.1.2.1 Innovative concept of interactive clothing and IoC

This research pioneered the concept and definition of interactive clothing in academia, puts forward its origin and function, explains its technical characteristics in the view of information science and the social characteristics from the perspective of the humanities science through the R&D roadmap model and development practice of a series of prototypes (partial reference model of Figure 4 and 26). Also explored the development direction of smart clothing in the future and analyzed the possibility of realizing internet of clothes (IoC) based on CPS/IoT technology (Model of Figure 16, 17, 24 and 25).

7.1.2.2 Models for researching the humanistic and technical attributes of interactive clothing

At the psychological level of humanistic perspective, interactive clothing needs to meet the “Self-esteem needs”, and it is necessary to satisfy the function of “Connotation” in the sociology of clothing, and it belongs to the “Couture fashion” category in clothing design typology (models of Figure 23, 24).

From the technical perspective, interactive clothing needs to meet “Wisdom” requirements in IoT data theory, “Cognition” functionality in the 5C architecture of CPS, and the transmission of “Humanistic symbols” regarding technical processes (models of Figure 23, 25).

7.1.2.3 Constructing an innovative Cyber-Physical-Clothing Systems architecture

At present, the academic has not yet proposed a complete technical process model for the prototype development of smart clothing or interactive clothing. This research pioneer summarized the flow of interactive clothing design and development and revealed the technical relevance of interactive clothing, DIKWS, and CPS in the Cyber-Physical-Clothing Systems (CPCS) model (model of Figure 27). And also, this research verified its feasibility with the interactive clothing prototyping as a case.

The role of this CPCS model is to explain the technical development process of interactive clothing from clothing to data, information, knowledge, wisdom, services, humans, and then back to clothing (C2H for short) in the perspective of CPS and DIKWS architecture. The interactive clothing has the characteristics of information processing and human feedback, it is controlled by machine-based algorithms and integrated the network with its wearers into one unified holistic framework, which determines its interactive architecture can be divided into three levels: physical level, cyber level, and social level. Each level uses different techniques and has different effects. This model provides specific technical guidance for the development of interactive clothing and even prototypes involving larger categories of smart clothing.

7.1.2.4 Revealed the innovative “C” design principle

Revealed the design principles of interactive clothing from the perspective of humanities and technology respectively, and guides the design of interactive clothing (model of Figure 55)

By summarizing the implementation process of case studies, 18 design principles of interactive clothing with letter C as the first letter was distilled. The specific links include essential aspects, information engineering aspects, art design aspects, objective aspects, and organizational aspects. The specific elements include: (1) Clothing; (2) Consumer-centered; and (3) Culture symbol; (4) CPCS; (5) Connection; (6) Conversion; (7) Computing; (8) Communication; (9) Control; (10) Cognition; (11) Configuration; (12) Critical thinking; (13) Creativity; (14) Communication; (15) Convenience; (16) Characterize; (17) Captivating symbol; and (18) Collaboration.

7.1.2.5 Established a framework of evaluation criteria for interactive clothing design

Established a basic framework of interactive clothing design evaluation criteria system, to encourage the object of evaluation to develop in the right direction and objectives. Up to now, although some scholars have put forward individual evaluation methods for case studies, the academic evaluation criteria of smart clothing has not been established, and interactive clothing as a new type of smart clothing cannot expect the existence of targeted evaluation criteria.

We divide the hierarchy of interactive clothing evaluation criteria into five levels: Target level, Perspective level, Criterion level, Index level, and Element level. This framework takes interactive clothing as the main body, with humanistic and technical perspective as the wings. Subjective evaluation criteria consist of emotion and aesthetics indexes, and objective criteria include function, ergonomics and the application of emerging technologies indexes, etc. Also, each indicator contains multiple subdivided elements (model of Figure 56).

7.2 Future research

Although the research of this project has achieved several results in both theoretical and practical links, there are still limitations. To be ready implemented in many fields of interpersonal interaction realized through clothing media, some extended research is crucial to be done, and future research needs to be focused on the following issues:

- It needs continue to develop the automatic interactive response function of clothing made to the wearer's physiology and psychology.

In the prototype development process of this project, case prototype 1 used temperature and humidity sensing technology, case prototype 2 and 3 only used distance sensing. The interaction effects of case prototype 2 and 3 are limited to clothing, not interaction between people. This sensing technology cannot reflect the physiological changes of the wearer, nor can it reflect the interactive communication caused by the physiological and psychological changes of different wearers. As a result, emerging technologies such as electrocardiography (ECG) need to be introduced into prototype development.

This study use questionnaire for emotional evaluation by Kansei methods, but it is basically same to SD methods. The technology of affective computing, including recognition of facial expression or bio-sensor for arousing, will be adopted to the CPS & IoT application research in future.

- It needs continue to conduct interdisciplinary research, establish a database of human physiological and psychological responses related to clothing life, and continue to optimize

the CPS algorithm.

Similar to autopilot technology, it can automatically execute different procedures according to different environmental changes and safely arrive at the destination. In order to realize that the individual or group of dressers can be reflected instantly through the clothing medium according to different physiological and psychological reactions in the process of interpersonal communication, it is necessary to establish a huge database of physiological and psychological changes, refine the index, and optimize the index data with people's social communicative symbols through the algorithm optimization. This is a huge and arduous, long-term scientific research task and scientific research vision.

Bibliography

- Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, Vol. 50 No. 2, pp.179-211.
- Alhafidh, B. M. H., & Allen, W. H. (2017, June). High Level Design of a Home Autonomous System Based on Cyber Physical System Modeling. In *Proceedings of the IEEE 37th International Conference on Distributed Computing Systems Workshops (ICDCSW)*. IEEE, Atlanta, GA, USA, pp. 45-52.
- Amft, O., & Lukowicz, P. (2009). From backpacks to smartphones: past, present, and future of wearable computers. *IEEE Pervasive Computing*, Vol. 8 No.3, pp. 8-13.
- Ariyatun, B., & Holland, R. (2003). A strategic approach to new product development in smart clothing. In *Proceedings of the 6th Asian Design Conference* (Vol. 70). October 14-17, Tsukuba, Japan
- Ariyatun, B., Holland, R., Harrison, D., & Kazi, T. (2005). The future design direction of smart clothing development. *Journal of the Textile Institute*, Vol. 96 No. 4, pp. 199-210.
- Bahadir, S. K., Cebi, S., Kahraman, C., & Kalaoglu, F. (2013). Developing a smart clothing system for blinds based on information axiom. *International Journal of Computational Intelligence Systems*, Vol. 6 No. 2, pp. 279-292.
- Bakker, S., & Niemantsverdriet, K. (2016). The interaction-attention continuum: considering various levels of human attention in interaction design. *International Journal of Design*, Vol.10 No. 2, pp. 1-10.
- Barfield, W. (ed.) (2015). *Fundamentals of wearable computers and augmented reality* (2nd ed.), CRC Press, London.
- Barnaghi, P., Sheth, A., Singh, V., & Hauswirth, M., (2015). Physical-Cyber-Social Computing: Looking Back, Looking Forward. *IEEE Internet Computing*, Vol. 19 No. 3, pp. 7-11.
- Barnard, M. (2002). *Fashion as communication*, Routledge, London.
- Barthes, R. (1964). Éléments de sémiologie. *Communications*, Vol.4 No.1, pp.91-135.
- Barthes, R. (1983). *The fashion system*. Berkeley: University of California Press.
- Bass, T. A. (1985). *The eudaemonic pie*. Houghton Mifflin Harcourt. USA.
- Baurley, S. (2003). Interactive and Experiential Design in Smart Textile Products and Applications, In *Proceeding of International Textile Design and Engineering Conference (INTEDEC): Fibrous Assemblies at the Design and Engineering Interface*, Edinburgh,

Scotland, 22nd-24th September 2003.

- Baurley, S. (2004). Interactive and experiential design in smart textile products and applications. *Personal and Ubiquitous Computing*, Vol. 8 No. 3-4, pp. 274-281.
- Bellinger, G., Castro, D., & Mills, A. (2004). *Data, information, knowledge, and wisdom*. Retrieved 7 January 2009.
- Bian, X. Y. (1998). Category System about Women's Apparel Brands in China. *Journal of China Textile University*, Vol. 24, pp. 105-109.
- Blunter, H. (1994). Society as symbolic interaction. In Reynolds & Herman, (Eds.) *Symbolic interaction: An introduction to social psychology*. pp. 263-266. AltaMira Press. New York.
- Bohn, C. (2004). Clothing as medium of communication. *Alemania. Traducido de la versión alemana: "Kleidung als Kommunikationsmedium, in dies., Inklusion, Exklusion und die Person". Konstanz (2006)*, pp. 95-127.
- Brighouse, H., & Swift, A. (2014). *Family values: The ethics of parent-child relationships*. Princeton University Press, Oxford.
- Broadhurst, S., & Price, S. (Eds.) (2017). *Digital Bodies: Creativity and Technology in the Arts and Humanities*. Springer, London
- Buchanan, R. (2001). Human dignity and human rights: Thoughts on the principles of human-centered design. *Design issues*, Vol.17 No.3, pp. 35-39.
- Chen, J., Ma, J., Zhong, N., Yao, Y., Liu, J., Huang, R., ... & Gao, Y. (2016). WaaS—Wisdom as a service. In Zhong, N., et al (eds.) *Wisdom Web of Things*. Springer, Cham, pp. 27-46.
- Chen, M., et al. (2017). Wearable 2.0: Enabling human-cloud integration in next generation healthcare systems. *IEEE Communications Magazine*, Vol. 55 No. 1, pp. 54-61.
- Chen, M., Ma, Y., Song, J., Lai, C. F., & Hu, B. (2016). Smart clothing: Connecting human with clouds and big data for sustainable health monitoring. *Mobile Networks and Applications*, Vol. 21 No. 5, pp. 825-845.
- Chen, M., Zhou, P., & Fortino, G. (2017). Emotion Communication System. *IEEE Access*, Vol. 5, pp. 326-337.
- Chevalier, M., & Mazzalovo, G. (2008). *Luxury brand management: a world of privilege*. John Wiley & Sons, Singapore.
- Cho, G. (Ed.) (2009). *Smart clothing: technology and applications*. CRC Press. Boca Raton.
- Cho, G., Lee, S., & Cho, J. (2009). Review and reappraisal of smart clothing. *International Journal of Human-Computer Interaction*, Vol. 25 No.6, pp. 582-617.

- Chun, J., & Lee, M. (2016). Developing a SEIL (Smart Enjoy Interact Light) bag utilizing LED display. *International Journal of Clothing Science and Technology*, Vol. 28 No. 2, pp. 233-253.
- Clarke, S. E. B., & O'Mahony, M. (1998). *Techno textiles: revolutionary fabrics for fashion and design*. Thames and Hudson.
- De Acutis, A., & De Rossi, D. (2017). e-Garments: Future as Second Skin?. In Stefan Schneegass and Oliver Amft Editors: *Smart Textiles*, Springer International Publishing, pp. 383-396.
- Desmet, P. M. A. (1999). To love and not to love: Why do products elicit mixed emotions. In *Proceedings of the 1st International Conference on Design and Emotion* (pp. 67-74). November 5, 1999. Delft: Delft University of Technology.
- Desmet, P. M. A., & Hekkert, P. (2009). Special issue editorial: Design & emotion. *International Journal of Design*, Vol. 3 No. 2, pp. 1-6
- Devendorf, L., Lo, J., Howell, N., Lee, J. L., Gong, N. W., Karagozler, M. E., ... & Ryokai, K. (2016, May). I don't Want to Wear a Screen: Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM. San Jose, CA, USA, pp. 6028-6039.
- Duarte Filho, N., Botelho, S., Bichet, M., dos Santos, R. P., Schroeder, G., Nagel, R., ... & Pereira, C. E. (2015). Human Computer Interface (HCI) for Intelligent Maintenance Systems (IMS): The Role of Human and Context. In *Engineering Asset Management-Systems, Professional Practices and Certification*. Springer, Cham, pp. 215-227.
- Dunlap, K. (1928). The development and function of clothing. *The Journal of General Psychology*, Vol. 1 No. 1, pp. 64-78.
- Feinberg, R.A., Mataro, L. and Burroughs, W. J. (1992). Clothing and social identity. *Clothing and Textiles Research Journal*, Vol. 11 No. 1, pp. 18-23.
- Flügel, J. C. (1930). *The Psychology of Clothes*. Hogarth Press, London.
- Forman, D. (2001). Wearable Computing, *Computer Buyer's Guide and Handbook*, October, 25-36.
- Gepperth, J. (2012). Smart Things: Wearables & Clothing, *Advances in Media Technology: Smart Things*, Vol. 3, pp. 41-48.
- Giacomin, J. (2014). What Is Human Centred Design? *The Design Journal*, Vol. 17 No.4, pp. 606-623.
- Gilligan, I. (2010). The prehistoric development of clothing: archaeological implications of a thermal model. *Journal of Archaeological Method and Theory*, Vol. 17 No. 1, pp. 15-80.
- Gould, P. (2003). Textiles gain intelligence. *Materials today*, Vol. 6 No. 10, pp. 38-43.

- Gu, Z. Y; Chen, L. (2006). *Intelligent Textile Design and Application*. Chemical Industry Press, Beijing.
- Hanuska, A., Chandramohan, B., Bellamy, L., Burke, P., Ramanathan, R., & Balakrishnan, V. (2016). *Smart clothing market analysis*. University of California Berkeley.
- Harms, E. (1938). The psychology of clothes. *American Journal of Sociology*, Vol. 44 No. 2, pp. 239-250.
- Honarvar, M. G., & Latifi, M. (2016). Overview of wearable electronics and smart textiles. *Journal of the Textile Institute Proceedings & Abstracts*, Vol. 108 No. 4, pp. 631-652.
- Hsiao, C. P., Li, R., Yan, X., & Do, E. Y. L. (2015) January. Tactile teacher: Sensing finger tapping in piano playing. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, Stanford, California, USA, pp. 257-260
- Hsu, H. J. and Burns, L. D. (2002). *Clothing evaluative criteria: a cross-national comparison of Taiwanese and United States consumers*, *Clothing & Textiles Research Journal*, Vol. 20 No. 4, pp. 246-252.
- Huang, R., Zhao, X., & Ma, J. (2014). The contours of a human individual model based empathetic u-pillbox system for humanistic geriatric healthcare. *Future Generation Computer Systems*, Vol. 37, pp. 404-416.
- Huang, W., Li, J., & Alem, L. (2018). Towards Preventative Healthcare: A Review of Wearable and Mobile Applications. *Studies in health technology and informatics*, Vol. 251, pp. 11-14.
- Hwang, C., Chung, T. L., & Sanders, E. A. (2016). Attitudes and purchase intentions for smart clothing: Examining US consumers' functional, expressive, and aesthetic needs for solar-powered clothing. *Clothing and Textiles Research Journal*, Vol.34 No. 3, pp. 207-222.
- Jagelka, M., *et al.* (2016, April). Wearable healthcare electronics for 24-7 monitoring with focus on user comfort. In *Proceedings of the Radioelektronika 26th International Conference*, IEEE. Kosice, Slovakia, pp. 5-9.
- Jeon, M., (Ed.). (2017). *Emotions and affect in human factors and human-computer interaction*. Academic Press, London.
- Jiang, R. N. (2011). Derivation Design from Haute Couture to Ready-to-wear Products. *China Textile Leader*, Vol. 6, pp. 92-93.
- Jones, S. J. (2005). *Fashion design*, Laurence King Publishing, pp. 34
- Kaiser, S. B. (1996). *The Social Psychology of Clothing: Symbolic Appearances in Context*, 2nd ed., Fairchild Books, London.
- Kaiser, S. B., (1996). *The social psychology of clothing: Symbolic appearances in context* (2nd

- ed.), Fairchild Books, London.
- Kan, V., Fujii, K., Amores, J., Zhu Jin, C. L., Maes, P., & Ishii, H. (2015, January). Social textiles: Social affordances and icebreaking interactions through wearable social messaging. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, New York, USA, pp. 619-624
- Karrer, T., Wittenhagen, M., Lichtschlag, L., Heller, F., & Borchers, J. (2011, May). Pinstripe: eyes-free continuous input on interactive clothing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Vancouver, BC, Canada, pp. 1313-1322.
- Keel, S. (2016). *Socialization: Parent–Child Interaction in Everyday Life*. Routledge, Oxon.
- Kelly, N. (2016). The WEAR Scale: Development of a measure of the social acceptability of a wearable device. *Graduate Theses and Dissertations*. 15230. Iowa State University.
- Kim, K., Joo, D., & Lee, K. P., (2010, April). Wearable-object-based interaction for a mobile audio device. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*. ACM, Atlanta, GA, USA, pp. 3865-3870.
- Kim, S., Roh, J. S., & Lee, E. Y. (2016). Development and Wearability Evaluation of All-Fabric Integrated Smart Jacket for a Temperature-regulating System Based on User Experience Design. *Fashion & Textile Research Journal*, Vol. 18 No. 3, pp. 363-373.
- Kim, Y. K., Wang, H., & Mahmud, M. S. (2016). Wearable body sensor network for health care applications. In Koncar, V. (Ed.) *Smart Textiles and Their Applications* (pp. 161-184). Woodhead Publishing, London.
- Kindness, P., Masthoff, J., & Mellish, C. (2017). Designing emotional support messages tailored to stressors. *International Journal of Human-Computer Studies*, Vol. 97, pp. 1-22.
- King-O'Riain, R. C. (2016). Enduring or Crossing Distance for Love? Negotiating Love and Distance in the Lives of Mixed Transnational Couples. *Sociological Research Online*, Vol. 21 No.1, pp. 1-10.
- Kittler, R., Kayser, M. and Stoneking, M. (2003). Molecular evolution of *pediculus humanus* and the origin of clothing. *Current Biology*, Vol. 13 No. 16, pp. 1414-1417.
- König, R. (1971). *Macht und Reiz der Mode*. Wien, Düsseldorf: Econ Verlag.
- Kosti, M. V., Georgiadis, K., Adamos, D. A., Laskaris, N., Spinellis, D., & Angelis, L. (2018). Towards an affordable brain computer interface for the assessment of programmers' mental workload. *International Journal of Human-Computer Studies*, Vol. 115, pp. 52-66.
- Krippendorff, K. (2006). *The semantic turn : A new foundation for design*. London, New York: Boca Raton.

- Lam Po Tang, S., & Stylios, G. K. (2006). An overview of smart technologies for clothing design and engineering. *International Journal of Clothing Science and Technology*, Vol. 18 No. 2, pp. 108-128.
- Lamb, J. M., & Kallal, M. J. (1992). A conceptual framework for apparel design. *Clothing and Textiles Research Journal*, Vol.10 No. 2, pp.42-47.
- Langer, S. K. (1953). *Feeling and form*. London: Routledge and Kegan Paul.
- Langer, S. K. (1957). *Problems of art: Ten philosophical lectures*. New York: Scribner.
- Larsen, R. J., & Diener, E. (1992). Promises and problems with the circumplex model of emotion. *Review of Personality and Social Psychology: Emotion*, Vol. 13, pp. 5-59.
- Lee, E. A. (2010, June). CPS foundations. In *Design Automation Conference (DAC), 2010 47th ACM/IEEE* (pp. 737-742). California, USA. IEEE.
- Lee, E. A. (2015). The past, present and future of cyber-physical systems: A focus on models. *Sensors*, Vol. 15 No. 3, pp.4837-4869.
- Lee, J., Bagheri, B., & Kao, H. A. (2014). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing Letters*, Vol 3, pp. 18-23.
- Lee, K. E. (2016). Female bike riders' clothing needs with the incorporation of wearable technology: Design and evaluation of wearers' perception of smart clothing within the cradle-to-cradle design framework. *Graduate Theses and Dissertations*. 16089. Iowa State University.
- Lee, S., Du Preez, W., & Thornton-Jones, N. (2005). *Fashioning the future: tomorrow's wardrobe*. Thames and Hudson. London, UK.
- Lee, S., Harada, A., & Stappers, P. J. (2002). Pleasure with products: Design based on kansei. In: Jordan, P.W., and Green, W. S. (eds.), *Pleasure-based Human Factors Seminar*, CRC Press, London. pp. 219-229.
- Leeds-Hurwitz, W. (2012). *Semiotics and communication: Signs, codes, cultures*. Routledge.
- Lennon, S.J. and Davis, L.L. (1989a). Clothing and human behavior from a social cognitive framework – part I: theoretical perspectives. *Clothing and Textiles Research Journal*, Vol. 7 No. 4, pp. 41-48.
- Lennon, S.J. and Davis, L.L. (1989b). Clothing and human behavior from a social cognitive framework – part II: the stages of social cognition. *Clothing and Textiles Research Journal*, Vol. 8 No. 1, pp. 1-9.
- Leonard, L. (2017). *U.S. Patent No. 9,582,973*. Washington, DC: U.S. Patent and Trademark Office.
- Liew, A. (2007). Understanding data, information, knowledge and their inter-relationships. *Journal of knowledge management practice*, Vol. 8 No.2, pp. 1-16.

- Locke, J. (1690). *An essay concerning human understanding*.
- Longo, F., Nicoletti, L., & Padovano, A., 2017. Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. *Computers & industrial engineering*, Vol. 113, pp. 144-159.
- Lv, J; Chen, D. (2016). Application and development trend of smart clothing. *Journal of Chengdu Textile College*, Vol. 33 No, 3, pp. 211-213.
- Mana, T. S. C., *et al.* (2016, December). Reducing Skin and Clothing Contamination of Healthcare Personnel by Improving Ease of Removal of Isolation Gowns, In *Open Forum Infectious Diseases*, Oxford University Press, Vol. 3, No. suppl_1.
- Mann, S. (1996). Smart Clothing, <http://wearcam.org/smart_clothing/node1.html> [Internet] [Accessed 6 July, 2018].
- Mann, S. (1997, February). "Smart clothing": wearable multimedia computing and "personal imaging" to restore the technological balance between people and their environments. In *Proceedings of the fourth ACM international conference on Multimedia* (pp. 163-174). Boston, Massachusetts, USA, November 18-22, ACM.
- Marazziti, D., *et al.* (2017). Decreased lymphocyte dopamine transporter in romantic lovers. *CNS spectrums*, Vol. 22 No. 3, pp. 290-294.
- Maslow, A. H. (1943). A theory of human motivation. *Psychological Review*, Vol. 50, pp. 370-396.
- Maslow, A. H. (1968). *Toward a psychology of being* (2nd Ed.). New York: Van Nostrand Reinhold Company.
- McCann, J., & Bryson, D. (Eds.). (2009). *Smart clothes and wearable technology*. Elsevier.
- McDonough, W., & Braungart, M. (2002). *Remaking the way we make things: Cradle to cradle*. New York: North Point Press. ISBN, 1224942886, 104.
- McLeod, S. (2007). Maslow's hierarchy of needs. *Simply Psychology*, 1.
- Meoli, D. and May-Plumlee, T. (2002). Interactive Electronic Textile Development: A Review of Technologies, *Journal of Textile and Apparel, Technology and Management*, Vol. 2 No. 2, pp. 1-12.
- Morgado, M. A. (1993). Animal Trademark Emblems on Fashion Apparel: A Semiotic Interpretation: Part II. Applied Semiotics. *Clothing and Textiles Research Journal*, Vol. 11 No. 3, pp. 31-38.
- Nagai, Y. (2015). A sense of design: The embedded motives of nature, culture, and future. In: Taura, T. (Ed.) *Principia Designae-Pre-Design, Design, and Post-Design*, Springer, Japan, pp. 43-59.
- Nagamachi, M. (2011). Kansei/affective engineering and history of kansei/affective

- engineering in the world. *Kansei/Affective Engineering*, Vol. 13, pp. 1-12.
- Nagamachi, M. (Ed.). (2011). *Kansei/Affective Engineering*. CRC Press, New York.
- Naibitt, J., & Bisesi, M. (1983). Megatrends: Ten new directions transforming our lives. *Sloan Management Review (pre-1986)*, Vol. 24 No. 4, pp. 69.
- Nelson, H. G., & Stolterman, E. (2012). *The Design Way: Intentional Change in an Unpredictable World* (2nd ed.), MIT Press, Cambridge.
- Ning, H., Liu, H., Ma, J., Yang, L. T., & Huang, R. (2016). Cybermatics: Cyber–physical–social–thinking hyperspace based science and technology. *Future generation computer systems*, Vol. 56, pp. 504-522.
- Nonaka I., Takeuchi H. (1995). *The Knowledge-Creating Company*, New York: Oxford University Press.
- Nonaka, L., Takeuchi, H., & Umemoto, K. (1996). A theory of organizational knowledge creation. *International Journal of Technology Management*, Vol. 11 No. 7/8, pp. 833-845.
- Norman, D. A. (2005). Human-centered design considered harmful. *Interactions*, Vol.12 No. 4, pp. 14-19.
- Norman, D.A. (2004). *Emotional design: Why we love (or hate) everyday things*, Basic Books, New York.
- O'Mahony, M. (2002). *Cyborg: The man-machine*. Thames & Hudson, London, England.
- Orth, M., Post, R., & Cooper, E. (1998, April). Fabric computing interfaces. In *CHI 98 conference summary on Human factors in computing systems* (pp. 331-332). Los Angeles, 18-23, April, 1998, ACM.
- Owyong, Y.S.M. (2009). Clothing semiotics and the social construction of power relations. *Social Semiotics*, Vol. 19 No. 2, pp. 191-211.
- Pan, Y., et al. (2017). Cooperation in lovers: An fNIRS-based hyperscanning study. *Human Brain Mapping*, Vol. 38 No.2, pp. 831-841.
- Park, S., Chung, K. and Jayaraman, S. (2014). Wearables: fundamentals, advancements, and a roadmap for the future. In Sazonov, E. and Neuman, M.R. (Eds), *Wearable Sensors: Fundamentals, Implementation and Applications*, Elsevier, New York, NY, pp. 1-23.
- Pedersen, E. (1923). The Psychology of Clothing. *The Iowa Homemaker*, Vol. 3 No. 12, pp. 11, 23-24.
- Perovich, L., Mothersill, P., & Farah, J. B. (2014, February). Awakened apparel: embedded soft actuators for expressive fashion and functional garments. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*, Munich, Germany, ACM, New York, pp. 77-80.

- Persson, N. K., Martinez, J. G., Zhong, Y., Maziz, A., & Jager, E. W. (2018). Actuating Textiles: Next Generation of Smart Textiles. *Advanced Materials Technologies*, Vol. 3 Issue 10. 1700397.
- Poston, B. (2009). An exercise in personal exploration: Maslow's Hierarchy of Needs. *The Surgical Technologist*, Vol.1, pp. 348-353.
- Rafaeli, A., & Vilnai-Yavetz, I. (2003). Discerning organizational boundaries through physical artifacts. In: Paulsen, N. and Hernes, T. (Eds.), *Managing boundaries in organizations: Multiple perspectives*, Palgrave Macmillan, UK. pp. 188-210.
- Rafaeli, S., Sudweeks, F., & McLaughlin, M. (1998). Interactivity on the Nets. *Network and netplay: Virtual groups on the Internet*, pp. 173-189. Mit Press.
- Rajkumar, R., Lee, I., Sha, L., & Stankovic, J., (2010, June). Cyber-physical systems: the next computing revolution. In *Proceeding of the Design Automation Conference (DAC), 2010 47th ACM/IEEE* (pp. 731-736). IEEE.
- Randell, C. (2001). Computerized clothing will benefit textile manufacturers. *Technical Textiles International*, Vol. 10 No.7, pp. 3-28.
- Rantanen, J., Alfthan, N., Impio, J., Karinsalo, T., Malmivaara, M., Matala, R., ... & Vanhala, J. (2000, October). Smart clothing for the arctic environment. In *Proceeding of the Fourth International Symposium on Wearable Computers*, (pp. 15-23). IEEE. Atlanta, Georgia, 18 - 21 October, 2000.
- Rapisarda, C. (2016). U.S. Patent No. 9,445,641. Washington, DC: U.S. Patent and Trademark Office.
- Roach, M. F., & Eichler, J. B. (1979). The language of personal adornment. In J. M. Cordwell, & R. A. Schwarz (Eds): *The fabrics of culture-The anthropology of clothing and adornment*, pp. 7-22. The Hague: Mouton.
- Rowley, J., Hartley, R. (2008). *Organizing Knowledge: An Introduction to Managing Access to Information*. London: Routledge.
- Sahlins, M. (1976). *Culture and practical reason*. Chicago: University of Chicago Press.
- Salim, F., Prohasky, D., Belbasis, A., Houshyar, S., & Fuss, F. K. (2014, September). Design and evaluation of smart wearable undergarment for monitoring physiological extremes in firefighting. In *Proceedings of the 2014 ACM International Symposium on Wearable Computers: Adjunct Program*. pp. 249-254. ACM, Seattle, WA, USA
- Sazonov, E., & Neuman, M. R. (Eds.). (2014). *Wearable Sensors: Fundamentals, implementation and applications*. Elsevier.
- Schüll, N. D. (2016). Data for life: Wearable technology and the design of self-care. *BioSocieties*, Vol. 11 No. 3 pp. 317–333.

- Schütte, S. T., Eklund, J., Axelsson, J. R., & Nagamachi, M. (2004). Concepts, methods and tools in Kansei engineering. *Theoretical Issues in Ergonomics Science*, Vol. 5 No. 3, pp. 214-231.
- Schwartz, M., (Ed). (2002). *Encyclopaedia of Smart Materials.*, New York: Wiley
- Sheth, A., Anantharam, P., & Henson, C. (2013). Physical-cyber-social computing: An early 21st century approach. *IEEE Intelligent Systems*, Vol. 28 No. 1, pp. 78-82.
- Sommer, C. M., & Wind, T. (1986). *Menschen, stile, kreationen*. Frankfurt/Main: Ullstein.
- Spillers, F. (2004). Emotion as a cognitive artifact and the design implications for products that are perceived as pleasurable. *Experience Dynamics*. Available at: <https://www.experiencedynamics.com/sites/default/files/publications/Emotion-in-Design%20.pdf> (accessed 9 February 2017).
- Stead, L., Goulev, P., Evans, C., & Mamdani, E. (2004). The emotional wardrobe. *Personal and Ubiquitous Computing*, Vol. 8 No. 3-4, pp. 282-290.
- Steen, M. (2012). Human-centered design as a fragile encounter. *Design Issues*, Vol.28 No. 1, pp. 72-80.
- Steffen, D. (2009). Categorizing product meaning: an investigation into the product language of clothing and fashion. In Chen, et al (EDs): *Proceedings of Design and semantics of form and movement* (pp. 73-81). October 26-27, Taipei, CHN.
- Steffen, D., & Françoise Adler & Marin, A. W. (2009). Smart Semantics. Product Semantics of Smart Clothes, In *Proceedings of IASDR 2009 (International Association of Societies of Design Research)*, Seoul, Korean, Society of Design Science, pp. 79-88.
- Suh, M., Carroll, K. E., & Cassill, N. L. (2010). Critical review on smart clothing product development. *Journal of textile and apparel, technology and management*, Vol.6 No.4, pp. 1-18.
- Swanson, J. (2014). *The Wonderful World of Wearable Devices*. The Rosen Publishing Group, Inc. New York, NY.
- Takagi, T. (1990). A concept of intelligent materials. *Journal of intelligent material systems and structures*, 1(2), 149-156.
- Tao, X. M. (2006), Interactive fabrics and Smart Textiles. In: *Proceedings of the China Science Association annual conference*. Beijing, pp.116-125.
- Tao, X. M. (Ed.), (2001). *Smart fibres, fabrics and clothing: fundamentals and applications*. CRC Press, Cambridge, England.
- Tao, X. M. (Ed). (2005). *Wearable electronics and photonics*, Elsevier, CRC Press, Cambridge, England.
- Tay, L. and Diener, E. (2011). Needs and subjective well-being around the world. *Journal of*

- personality and social psychology*, Vol. 101 No. 2, pp. 354-365.
- Thorp, E. O. (1966). *Beat the Dealer: a winning strategy for the game of twenty one*. Vintage.
- Thorp, E. O. (1998, October). The invention of the first wearable computer. In *Wearable Computers, 1998. Digest of Papers. Second International Symposium on* (pp. 4-8). IEEE.
- Toups, M. A., Kitchen, A., Light, J. E. and Reed, D. L. (2010). Origin of clothing lice indicates early clothing use by anatomically modern humans in Africa, *Molecular Biology & Evolution*, Vol. 28 No. 1, pp. 29-32.
- Trindade, I. G., Machado da Silva, J., Miguel, R., Pereira, M., Lucas, J., Oliveira, L., ... & Santos Silva, M., 2016. Design and evaluation of novel textile wearable systems for the surveillance of vital signals. *Sensors*, Vol. 16 No. 10, pp. 1573. <https://doi.org/10.3390/s16101573>
- Twigg, J. (2009). Clothing, identity and the embodiment of age. In Powell, J. and Gilbert, T. (Eds), *Aging and Identity: A Postmodern Dialogue*, Nova Science Publishers, New York, NY, pp. 93-104.
- Van Langenhove, L., & Hertleer, C. (2004). Smart clothing: a new life. *International journal of clothing science and technology*, Vol. 16 No. 1-2, pp. 63-72.
- Waddell, G. (2004). *How fashion works: Couture, ready-to-wear and mass production*, Blackwell Science Publishing Ltd., Oxford, UK.
- Wang, W. Z., Nagai, Y., Fang, Y., Qiao, C. X., & Chen, Y. P., (2018). Design optimization for interactive parent-child clothing: integration of IoT technology entities and emotional virtual bodies. In *DS92: Proceedings of the DESIGN 2018 15th International Design Conference* (pp. 2347-2356), Dubrovnik, Croatia.
- Wang, W., Nagai, Y., Fang, Y., & Maekawa, M. (2018). Interactive technology embedded in fashion emotional design: Case study on interactive clothing for couples. *International Journal of Clothing Science and Technology*. Vol. 30 No. 3, pp. 302-319
- Wang, W., Yao, L., Cheng, C. Y., Zhang, T., Atsumi, H., Wang, L., ... & Zhou, K. (2017). Harnessing the hygroscopic and biofluorescent behaviors of genetically tractable microbial cells to design biohybrid wearables. *Science advances*, Vol.3 No.5, e1601984.
- Wang, W.Z., et al. (2014). Design for mutual transformation between outdoor wear and camping tent. *International Journal of Clothing Science and Technology*, Vol. 26 No. 4, pp. 291-304.
- Ward, J. (2001). Cold comfort yarn. *New Design*, Vol. 5, pp. 32-33.
- Wei, B. Z. (2014). *Hot technology patent early warning analysis-wearable computing fascicle*. Intellectual property press. Beijing.

- Weizhen, W., Nagai, Y., & Yuan, F. (2017). Human-centred design blending smart technology with emotional responses: Case study on interactive clothing for couples. In *DS 87-8 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 8: Human Behaviour in Design* (pp. 51-58), Vancouver, Canada, August 21-25, 2017. The Design Society, Glasgow.
- Wensveen, S., Overbeeke, K., & Djajadiningrat, T. (2002, June). Push me, shove me and I show you how you feel: recognising mood from emotionally rich interaction. In *Proceedings of the 4th Conference on Designing Interactive Systems: Processes, practices, methods, and techniques*. London, England, ACM, pp. 335-340.
- Wright, R., & Keith, L. (2014). Wearable technology: If the tech fits, wear it. *Journal of Electronic Resources in Medical Libraries*, Vol. 11 No. 4, pp. 204-216.
- Yan, Y. F., Wang, S., Chen, X. L. & Li, Z. (2016). Research and development situation analysis of wearable devices international patent technology. *Advanced Materials Industry*, Vol.12, pp. 14-22.
- Yao, L., Ou, J., Cheng, C. Y., Steiner, H., Wang, W., Wang, G., & Ishii, H. (2015, April). BioLogic: natto cells as nanoactuators for shape changing interfaces. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 1-10). ACM. New York, NY, USA.
- Yu, W., Fan, J., Ng, S. P., & Harlock, S. (2014). *Innovation and technology of women's intimate apparel*. Woodhead Publishing.
- Zhang, X. X. & TAO, X. M. (2001). Smart textiles (1): Passive smart, *Textile Asia*, Vol. 32 No. 6, pp. 45-49.
- Zins, C. (2007). Conceptual approaches for defining data, information, and knowledge. *Journal of the American society for information science and technology*, Vol. 58 No. 4, pp. 479-493.
- Zeleny, M. (2005). *Human systems management: Integrating knowledge, management and systems*. World Scientific.

Publications

1. Papers published in journals

- Weizhen Wang, Yukari Nagai, Yuan Fang, Masami Maekawa. Interactive technology embedded in fashion emotional design: Case study on interactive clothing for couples. *International Journal of Clothing Science and Technology*. Vol. 30 No. 3, 2018, pp. 302-319.
- Weizhen Wang, Yukari Nagai, Yuan Fang. Study on Parent-Child Clothing Design Combining IoT Technology and Humanistic Emotion. *ZHUANGSHI*. Vol. 303 No. 7, 2018, pp. 132-134.

2. International conference proceedings

- Wang Weizhen, Yukari Nagai, Fang Yuan. (2017). Human-centred design blending smart technology with emotional responses: Case study on interactive clothing for couples. In *DS 87-8 Proceedings of the 21st International Conference on Engineering Design (ICED 17)* Vol 8: Human Behaviour in Design, Vancouver, Canada, 21-25.08. 2017. pp. 51-58
- Wang Weizhen, Yukari Nagai, et al. (2018). Design Optimization for Interactive Parent-Child Clothing: Interaction of IoT Technology Entitles and Emotional Virtual Bodies. In *DS92: Proceedings of the DESIGN 2018 15th International Design Conference*, Dubrovnik, Croatia, May 21-24, 2018. pp. 2347-2356.

Appendix

Notes: The case study questionnaires are in the form of an online system

Case 1 <https://www.wjx.cn/pq/17687051.aspx?t=636782437723849202>

Case 2 <https://www.wjx.cn/jq/26162639.aspx>

The following is a partial presentation of the Case study 2 questionnaire.

Parent-child Clothing Questionnaire

The screenshot of the network pages are as follows

Parent-child clothing questionnaire 3 / 亲子装问卷系列之3

Dear all,

We are conducting a survey of design cases for parent-child clothing.
We would like to invite you to fill out this form.

NOTE: The objective of this questionnaire is to fill **ONLY** in the following categories of three groups: Garment Industry Practitioners Group, Information Science and Engineering Researchers Group and Children Parent Group. Other groups of netizens please avoid filling out this questionnaire!

This questionnaire is used for anonymous systems. All data are for statistical analysis only.
In the case of a 7-point scoring system, please score each case according to your own expertise and text hint.
It will take 15 minutes to finish.

Thank you for your cooperation!

*** 1. Is your current family status a father or a mother?**

☐ Yes ☐ No

*** 2. What is your gender?**

☐ Male ☐ Female

*** 3. What is your age range?**

☐ 18~29 ☐ 30~39 ☐ 40~49 ☐ 50~

*** 4. What type of dress concept do you think you belong to?**

☐ Traditional ☐ stylish ☐ Innovative ☐ Casual

*** 5. Which kind of group do you belong to our survey object?**

☐ Apparel industry practitioners
☐ Information science, photoelectric engineering and related professionals
☐ Parents of children

*** 6. In your family life, can you accept to wear a parent-child clothing with your baby and your family?**

☐ Yes ☐ No

Introduction of the style of the parent-child clothing involved in this questionnaire

1 Interactive style

This style refers to smart clothing that developed using Cyber-Physical Systems /Internet of Things technology. The distance, sound, movement between the pluralities of clothes (dressers) can automatically adjust the appearance, color, model of the clothing, and the intelligent interactive reaction is formed between many pieces of clothing.



2 Graffiti style

This style refers to the various patterns of clothing contrast strong, color blending. It is a very special, exaggerated or casual style that depicts the graphic, text or color in an abstract sense.



3 National style

This style refers to the clothing that combines the elements of traditional national costumes, combined with the needs of modern life, social and other occasions, with both national elements and modern fashion design elements.



4 Casual style

This style of clothing refers to people wearing in an unrestrained and free leisure life, emphasizing a simple and natural style.



5 Classical dress style

The design of this style clothing is concise, elegant and dignified. It emphasizes the texture of the fabric and the fine cutting, and shows a classical beauty.



6 Deconstructive style

This style emphasizes the concept of unstructured design. It uses the concept of decomposition, emphasizing breaking, superimposing, reorganizing, attaching importance to the individual or the component itself, and opposing the overall unification to create fragmentation and uncertainty feeling.



Answer prompt :

For the clothing in the picture, do you expect the answer to the left or right vocabulary options?

Each vocabulary corresponding to the left and right sides of each line should select an answer, and each picture has a total of 24 lines corresponding to the evaluation vocabulary.

The seven dots per line are the seven options for the answer, please click on your recognized dots as an answer (such as Avant-garde or Conservative questions, if you feel that the clothing is the best avant-garde, you can choose -3 corresponding to the dot for your answer; If you think the clothing is more avant-garde, you can choose the vertical point corresponding to -2 or 1 points for your answer; If you think the clothing is very conservative, you can choose the vertical corresponding to 3 dot for your answer.

* 7. Style 1



	-3	-2	-1	0	1	2	3	
Avant-garde	☐	☐	☐	☐	☐	☐	☐	Conservative
Staid	☐	☐	☐	☐	☐	☐	☐	Lively
Exquisite	☐	☐	☐	☐	☐	☐	☐	Rough
Childlike	☐	☐	☐	☐	☐	☐	☐	Mature
Creative	☐	☐	☐	☐	☐	☐	☐	Monotonous
Elegant	☐	☐	☐	☐	☐	☐	☐	Vulgar
Fashionable	☐	☐	☐	☐	☐	☐	☐	Outdated
Cross-boundary	☐	☐	☐	☐	☐	☐	☐	Restricted
Concise	☐	☐	☐	☐	☐	☐	☐	Tedious
	-3	-2	-1	0	1	2	3	
Smart	☐	☐	☐	☐	☐	☐	☐	Rigid
Environmental	☐	☐	☐	☐	☐	☐	☐	Destructive
Flexible	☐	☐	☐	☐	☐	☐	☐	Bound
Technology	☐	☐	☐	☐	☐	☐	☐	Traditional
Interactive	☐	☐	☐	☐	☐	☐	☐	Isolated
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Systematic	☐	☐	☐	☐	☐	☐	☐	Messy
Multifunctional	☐	☐	☐	☐	☐	☐	☐	Single
Emotional	☐	☐	☐	☐	☐	☐	☐	Rational
Affinity	☐	☐	☐	☐	☐	☐	☐	Alienated
Warm	☐	☐	☐	☐	☐	☐	☐	Cold
Interesting	☐	☐	☐	☐	☐	☐	☐	Stodgy
Disappointed	☐	☐	☐	☐	☐	☐	☐	Surprise
Relaxed	☐	☐	☐	☐	☐	☐	☐	Gloomy
Enthusiastic	☐	☐	☐	☐	☐	☐	☐	Indifferent

* 8. Style 2



	-3	-2	-1	0	1	2	3	
Creative	☐	☐	☐	☐	☐	☐	☐	Monotonous
Elegant	☐	☐	☐	☐	☐	☐	☐	Vulgar
Fashionable	☐	☐	☐	☐	☐	☐	☐	Outdated
Cross-boundary	☐	☐	☐	☐	☐	☐	☐	Restricted
Concise	☐	☐	☐	☐	☐	☐	☐	Tedious
Smart	☐	☐	☐	☐	☐	☐	☐	Rigid
Environmental	☐	☐	☐	☐	☐	☐	☐	Destructive
Flexible	☐	☐	☐	☐	☐	☐	☐	Bound
Technology	☐	☐	☐	☐	☐	☐	☐	Traditional
	-3	-2	-1	0	1	2	3	
Interactive	☐	☐	☐	☐	☐	☐	☐	Isolated
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Systematic	☐	☐	☐	☐	☐	☐	☐	Messy
Multifunctional	☐	☐	☐	☐	☐	☐	☐	Single
Emotional	☐	☐	☐	☐	☐	☐	☐	Rational
Affinity	☐	☐	☐	☐	☐	☐	☐	Alienated
Warm	☐	☐	☐	☐	☐	☐	☐	Cold
Interesting	☐	☐	☐	☐	☐	☐	☐	Stodgy
Disappointed	☐	☐	☐	☐	☐	☐	☐	Surprise
Relaxed	☐	☐	☐	☐	☐	☐	☐	Gloomy
Enthusiastic	☐	☐	☐	☐	☐	☐	☐	Indifferent
Avant-garde	☐	☐	☐	☐	☐	☐	☐	Conservative
Staid	☐	☐	☐	☐	☐	☐	☐	Lively
Exquisite	☐	☐	☐	☐	☐	☐	☐	Rough
Childlike	☐	☐	☐	☐	☐	☐	☐	Mature

*9. Style 3



	-3	-2	-1	0	1	2	3	
Cross-boundary	☐	☐	☐	☐	☐	☐	☐	Restricted
Concise	☐	☐	☐	☐	☐	☐	☐	Tedious
Smart	☐	☐	☐	☐	☐	☐	☐	Rigid
Environmental	☐	☐	☐	☐	☐	☐	☐	Destructive
Flexible	☐	☐	☐	☐	☐	☐	☐	Bound
Technology	☐	☐	☐	☐	☐	☐	☐	Traditional
Interactive	☐	☐	☐	☐	☐	☐	☐	Isolated
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Systematic	☐	☐	☐	☐	☐	☐	☐	Messy
	-3	-2	-1	0	1	2	3	
Multifunctional	☐	☐	☐	☐	☐	☐	☐	Single
Emotional	☐	☐	☐	☐	☐	☐	☐	Rational
Affinity	☐	☐	☐	☐	☐	☐	☐	Alienated
Warm	☐	☐	☐	☐	☐	☐	☐	Cold
Interesting	☐	☐	☐	☐	☐	☐	☐	Stodgy
Surprise	☐	☐	☐	☐	☐	☐	☐	Disappointed
Relaxed	☐	☐	☐	☐	☐	☐	☐	Gloomy
Enthusiastic	☐	☐	☐	☐	☐	☐	☐	Indifferent
Avant-garde	☐	☐	☐	☐	☐	☐	☐	Conservative
Staid	☐	☐	☐	☐	☐	☐	☐	Lively
Exquisite	☐	☐	☐	☐	☐	☐	☐	Rough
Childlike	☐	☐	☐	☐	☐	☐	☐	Mature
Creative	☐	☐	☐	☐	☐	☐	☐	Monotonous
Elegant	☐	☐	☐	☐	☐	☐	☐	Vulgar
Fashionable	☐	☐	☐	☐	☐	☐	☐	Outdated

* 10. Style 4



	-3	-2	-1	0	1	2	3	
Avant-garde	☐	☐	☐	☐	☐	☐	☐	Conservative
Staid	☐	☐	☐	☐	☐	☐	☐	Lively
Exquisite	☐	☐	☐	☐	☐	☐	☐	Rough
Childlike	☐	☐	☐	☐	☐	☐	☐	Mature
Creative	☐	☐	☐	☐	☐	☐	☐	Monotonous
Elegant	☐	☐	☐	☐	☐	☐	☐	Vulgar
Fashionable	☐	☐	☐	☐	☐	☐	☐	Outdated
Cross-boundary	☐	☐	☐	☐	☐	☐	☐	Restricted
Concise	☐	☐	☐	☐	☐	☐	☐	Tedious
	-3	-2	-1	0	1	2	3	
Smart	☐	☐	☐	☐	☐	☐	☐	Rigid
Environmental	☐	☐	☐	☐	☐	☐	☐	Destructive
Flexible	☐	☐	☐	☐	☐	☐	☐	Bound
Technology	☐	☐	☐	☐	☐	☐	☐	Traditional
Interactive	☐	☐	☐	☐	☐	☐	☐	Isolated
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Systematic	☐	☐	☐	☐	☐	☐	☐	Messy
Multifunctional	☐	☐	☐	☐	☐	☐	☐	Single
Emotional	☐	☐	☐	☐	☐	☐	☐	Rational
Affinity	☐	☐	☐	☐	☐	☐	☐	Alienated
Warm	☐	☐	☐	☐	☐	☐	☐	Cold
Interesting	☐	☐	☐	☐	☐	☐	☐	Stodgy
Disappointed	☐	☐	☐	☐	☐	☐	☐	Surprise
Relaxed	☐	☐	☐	☐	☐	☐	☐	Gloomy
Enthusiastic	☐	☐	☐	☐	☐	☐	☐	Indifferent

* 11. Style 5



	-3	-2	-1	0	1	2	3	
Cross-boundary	☐	☐	☐	☐	☐	☐	☐	Restricted
Concise	☐	☐	☐	☐	☐	☐	☐	Tedious
Smart	☐	☐	☐	☐	☐	☐	☐	Rigid
Environmental	☐	☐	☐	☐	☐	☐	☐	Destructive
Flexible	☐	☐	☐	☐	☐	☐	☐	Bound
Technology	☐	☐	☐	☐	☐	☐	☐	Traditional
Interactive	☐	☐	☐	☐	☐	☐	☐	Isolated
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Systematic	☐	☐	☐	☐	☐	☐	☐	Messy
	-3	-2	-1	0	1	2	3	
Multifunctional	☐	☐	☐	☐	☐	☐	☐	Single
Emotional	☐	☐	☐	☐	☐	☐	☐	Rational
Affinity	☐	☐	☐	☐	☐	☐	☐	Alienated
Warm	☐	☐	☐	☐	☐	☐	☐	Cold
Interesting	☐	☐	☐	☐	☐	☐	☐	Stodgy
Disappointed	☐	☐	☐	☐	☐	☐	☐	Surprise
Relaxed	☐	☐	☐	☐	☐	☐	☐	Gloomy
Enthusiastic	☐	☐	☐	☐	☐	☐	☐	Indifferent
Avant-garde	☐	☐	☐	☐	☐	☐	☐	Conservative
Staid	☐	☐	☐	☐	☐	☐	☐	Lively
Exquisite	☐	☐	☐	☐	☐	☐	☐	Rough
Childlike	☐	☐	☐	☐	☐	☐	☐	Mature
Creative	☐	☐	☐	☐	☐	☐	☐	Monotonous
Elegant	☐	☐	☐	☐	☐	☐	☐	Vulgar
Fashionable	☐	☐	☐	☐	☐	☐	☐	Outdated

* 12. Style 6



	-3	-2	-1	0	1	2	3	
Technology	☐	☐	☐	☐	☐	☐	☐	Traditional
Interactive	☐	☐	☐	☐	☐	☐	☐	Isolated
Closed	☐	☐	☐	☐	☐	☐	☐	Open
Systematic	☐	☐	☐	☐	☐	☐	☐	Messy
Multifunctional	☐	☐	☐	☐	☐	☐	☐	Single
Emotional	☐	☐	☐	☐	☐	☐	☐	Rational
Affinity	☐	☐	☐	☐	☐	☐	☐	Alienated
Warm	☐	☐	☐	☐	☐	☐	☐	Cold
Interesting	☐	☐	☐	☐	☐	☐	☐	Stodgy
	-3	-2	-1	0	1	2	3	
Disappointed	☐	☐	☐	☐	☐	☐	☐	Surprise
Relaxed	☐	☐	☐	☐	☐	☐	☐	Gloomy
Enthusiastic	☐	☐	☐	☐	☐	☐	☐	Indifferent
Avant-garde	☐	☐	☐	☐	☐	☐	☐	Conservative
Staid	☐	☐	☐	☐	☐	☐	☐	Lively
Exquisite	☐	☐	☐	☐	☐	☐	☐	Rough
Childlike	☐	☐	☐	☐	☐	☐	☐	Mature
Creative	☐	☐	☐	☐	☐	☐	☐	Monotonous
Elegant	☐	☐	☐	☐	☐	☐	☐	Vulgar
Fashionable	☐	☐	☐	☐	☐	☐	☐	Outdated
Cross-boundary	☐	☐	☐	☐	☐	☐	☐	Restricted
Concise	☐	☐	☐	☐	☐	☐	☐	Tedious
Smart	☐	☐	☐	☐	☐	☐	☐	Rigid
Environmental	☐	☐	☐	☐	☐	☐	☐	Destructive
Flexible	☐	☐	☐	☐	☐	☐	☐	Bound

Parent-child clothing questionnaire 3 / 亲子装问卷系列之3



* 13. With the advance of science and technology, assuming that five years later, which one of the following parent-child clothing you would prefer to buy?



☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8

Thanks for Your Support! 🙏

Please press the last button to finish! 🙏

提交

问卷星 提供技术支持