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# DESIGN OPTIMIZATION FOR INTERACTIVE PARENT-CHILD CLOTHING: INTEGRATION OF IOT TECHNOLOGY ENTITIES AND EMOTIONAL VIRTUAL BODIES

W. Z. Wang, Y. Nagai, Y. Fang, C. X. Qiao and Y. P. Chen

## Abstract

In academia, this paper expounds the development trend of the interactive clothing through the inference of the pyramid hierarchy model in psychology, sociology and the data evolution theory. In practical, through the design of prototypes and the evaluation of Kansei engineering to demonstrate the characteristics of interactive parent-child clothing, validated the necessity of combining emotional design with high-tech application, provides a practical approach to realize the IoC (internet of clothes) cycle for the coming age of ubiquitous intelligent IoT applications.

*Keywords: parent-child clothing, smart clothing, emotional engineering, kansei engineering, internet of things (IoT)*

## 1. Introduction

The application of internet of things (IoT) technology to fashion industry is in the ascendanting situation. In recent years, researchers have generally focused on IoT approaches to implementing smart clothing design, with fruitful success in sports, health care and other fields (Bahadir et al., 2013; Perovich et al., 2014; Kan et al., 2015), and a small number of sportswear has been put on the market. According to the 2016 and 2017 Milan, Paris, New York, Tokyo and other major Fashion Week shows, especially the Fashion Tech Festival 2017 in Paris, more and more brands of product development and the effectiveness of the fashion show have adopted IoT technology. Undeniably, technological innovation can enhance the fashion brand's marketing campaign and catch consumers' great attention, IoT technology in future will integrated into our daily clothing life (Ariyatum et al., 2005; Wright and Keith, 2014; Schüll, 2016).

However, we are still confronting with the challenge from the concept that wearable technology is not fashionable enough to be part of our daily wardrobe. A long time ago, Naisbitt and 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; Wang et al., 2017), the expression function of emotion is an important design element which cannot be neglected in the development of smart clothing.

The question is how to get smart clothing into our emotional daily lives. In this study, we extracted the parent-child clothing, i.e., one typical carrier of the emotional design, as the research object. As a symbolic concept clothing, parent-child clothing expresses the integration of family belonging and clothing culture, sublimated into a spiritual category and cultural awareness (Brighouse and Swift, 2014). However, according to our questionnaire survey, many young parents do not agree with the

existing parent-child clothing on the market. The main reason is that these products are too formalized, not stylish or fashionable, and lack the effect of parent-child interaction.
Therefore, the aims of this study is to explore the new elements in optimizing the design for parent-child clothing, by relying on this design optimization platform to inquire a unique application form of combine innovative fashion, emotion design with demystifying IoT technology in the design of parent-child clothing, with realistic theoretical and applied research significance. The problems to be solved include Q1: How to realize the combination of parent-child clothing and IoT technology? Q2: How to enhance the emotional value of the smart parent-child clothing bases on the emotion design technique?
The remaining part of this paper is structured as follows: first, a literature review including four main areas (demand psychology, costume sociology, level type of costume design and IoT data evolution theory) and hypothesis are presented. Followed by methodology, we conducted a questionnaire survey, designed and implemented a series of prototypes. Finally, the data analysis approach and results are presented, concludes with discussion and conclusion section.

## 2. Related work and hypothesis

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 spiritual level to the physical level of humanistic and technical perspectives, the related research literatures are classified for building a pyramid deduction analysis model (Figure 1).

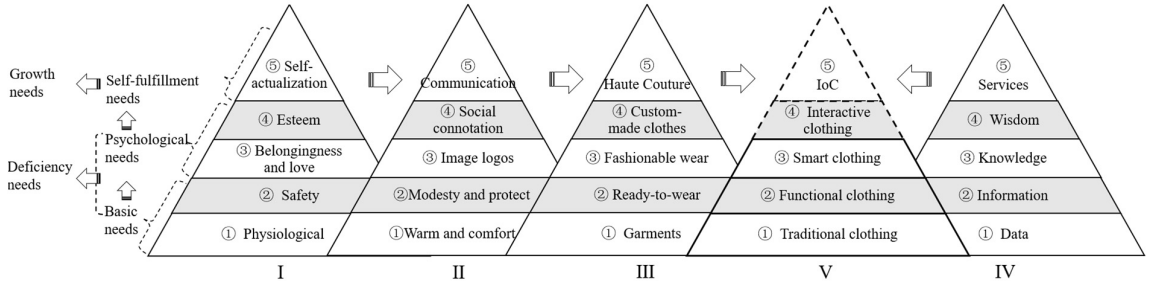


**Figure 1. The deduction model of smart clothing evolution in IoT era**

- Firstly, take Maslow's theory of demand psychology as the primitive angle of analysis. As Figure 1I shows, Maslow's Hierarchy of Needs Pyramid divide human needs into two categories (Deficiency and Growth needs) and three levels (Basic, Psychological and Self-fulfilment needs) from low-level to advanced, and is subdivided into five stages (e.g. physiological, safety, belongingness, esteem and self-actualization needs) (Maslow, 1970; Tay and Diener, 2011). We use this pyramid model as the primitive basis for deductive analysis.
- According to archaeological and social semiotics studies, garment has multiple attributes (Figure 1II). The interrelationships between attributes of garment and their evolutionary path, mainly includes five attributes or symbols ranging from low-level to advanced as follows. Warmth and comfort (Pedersen, 1923; Toups et al., 2010); modesty and protection (Dunlap, 1928; Kittler et al., 2003); logos (Harms, 1938; Gilligan, 2010); social and cultural connotations (Feinberg et al., 1992; Owyong, 2009); communication and expression (Barnard, 2002; Leeds-Hurwitz, 2012). By comparison, we found that the five main attributes of garment exactly match the five needs of Maslow's pyramid model.
- Integrated the design and production characteristics of clothing as well as the analysis perspective of the distribution cluster hierarchy (Figure 1III), clothing can be divided into garment, ready-to-wear, couture ready-to-wear, custom fashion and haute couture, five categories ranging from low-level to advanced (Waddell, 2004; Chevalier and Mazzalovo, 2012). These five levels are perfectly consistent with the garment attributes and Maslow's hierarchy of needs.
- According to IoT data evolution theory perspective (Figure 1IV), the rapid development of the IoT and Wisdom Web of Things accelerates the research to realize the organic amalgamation

and harmonious symbiosis among humans, computers and things in the cyber world (Baskarada and Koronios, 2013; Guo et al., 2013). This cyber world cycle "from things to data, information, knowledge, wisdom, services, humans, and then back to things" (Zhong et al., 2016; Ning et al., 2016). The ultimate goal of the cyber development cycle is still to serve people's daily life.

- According to smart clothing evolution perspective (Figure 1V), the pyramid level in this cyber world complete correspondence with the level of garment sociology and the demand psychology. At the same time, it also infers the conclusion that the development path of the smart clothing evolves from the ordinary clothing to the functional clothing, the smart clothing, the interactive clothing and the internet of clothes (IoC) (Wang et al., 2017). The focus of the combination of the smart clothing concept and IoT technology is the display form of interactive clothing and IoC.

Through the deduction analysis of the above five pyramid models, we should realize that the R&D trend of the smart clothing would move from the function of one piece of clothing to the interaction of multiple clothes approaching the IoT era. The parent-child clothing emphasizes parent-child interaction in everyday family life and family circle's emotional relations (Keel, 2016), which is also a micro-hyber world. Therefore, we have reason to infer that the introduction of IoT technology into the design and development of parent-child clothing, the concept of local area network to show the family atmosphere and space-time concept, will be an interesting and potentially promising research topic. Also provides a practical approach to realize the interactive IoC for the coming age of ubiquitous intelligent IoT applications. Therefore, we make the following research hypothesis:

- H.1 The application of IoT technology could enrich the design manifestation of parent-child clothing, and realize the variety of appearance style. IoT has a vast potential to improve quality of daily clothing life and provide new impetus for clothing innovation (Luis-Ferreira and Jardim-Goncalves, 2013; Pieroni et al., 2015; Min and Kim, 2017), as a fashion designer, we should try to apply these techniques.
- H.2 IoT technology introduced parent-child clothing design could enhance the added emotional value of parent-child relationship. New product development in the pursuit of technological progress, while not ignoring the value of human emotion (Norman, 2004; Park et al., 2014; Mazzoni and Bryan-Kinns, 2015; Min and Kim, 2017). The interactive clothing utilize a large number of sensors arises to develop solutions which implement a strong core architecture, and is flexible and modular enough to be combined with other IoT solutions (Perera et al., 2014), thereby forming a kind of emotional interaction between the clothes of different wearer.

## 3. Methodology

Methodologically, this study belongs to action research. The Approach, Deployment, Results and Improvement (ADRI) approach to evaluation of parent-child clothing considered, which is based on a literature review and deduction as well as carrying out the whole process from questionnaire investigation to clothing prototyping and Kansei engineering evaluation analysis.
The prototype development method is as follows:

- The clothing style design link, adopting the parents and the child's three pieces of family attire combination forms.
- Technical links, we use IoT sensing technology to establish the IoC local area network, and formate family clothing LAN world.
- The external manifestation of clothing links, we use the apparent effect of the LED form. Because the three major elements of clothing product design, that is, the style, colour and material belonging to the visual category, and the LED illumination effect is obvious.

## 4. Experimental approach

### 4.1. Design means of interactive technology realization

The first is the overall vision of the prototype design. The target wearers of the prototype design are the family trio, namely the father, mother and child's three pieces of clothing for one parent-child clothing series, with the IoC interactive effect that transcending the traditional parent-child clothing.
Second, the appearance design of the prototype. IoC is a future trend, so the shape of the clothing and the selection of the basic fabrics to be more avant-garde.
Finally, it is an interactive form of technical design. Assuming that the three pieces of clothing will form a variety of interactions with one another. The specific ideas are as follows:

- When child is close to father, their clothing produce a form change ① at the same time.
- When the distance between child and mother is close, their clothing produce a change ② simultaneously.
- When child and parents are close to the set distance at the same time, three pieces of clothing simultaneously causing the change of ③ species.
- When father and mother are close (at this time there is no child, so this can also be regarded as a lover clothing), their clothing also causes a kind of change ④.
- The reaction of a single piece of clothing. Every piece of clothing has its own self-reaction, i.e. ⑤, ⑥ and ⑦.

### 4.2. Material selection

In the fabric of clothing, 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 ventilation, corrosion resistance. After a 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.
In electronic components, each piece of clothing is independently using a microcontroller STC51 (Zhejiang Jiaxing Xinwei Electronic technology Co., Ltd.) as the main control chip to control the sensor response, LED control and the communication of three pieces of clothing. In the communication node, we use ARM CORTEX-M4 microprocessor as the main control chip. In the sensor selection, we use the horizontal KC_IRS (Shenzhen Xinyujia Electronic Technology Co., Ltd.) infrared sensor module. Two types of light strips are selected: The LED using FPC as the base plate can be arbitrarily curved flexible flat strip with 5050-60GRB model (Shanghai Jingzheng Lighting lamp Co., Ltd.), can be fixed to a variety of letters or patterns of shape. The EL cold light strip, can repeatedly folded and curved, power consumption is very low, suitable for use in clothing design, can achieve steady-slow, flash-fast and flash three kinds of effects.

### 4.3. Prototypes production and result

We design and produce a series of prototype as detailed in Figure 2. These prototypes of the fabric material and white, orange, black three colours combination embodies the sense of science and technology, three pieces of clothing colour and styling echoes, with interest and relevance. Women's wear with different colour stitching with a large area of white, stable and no lack of lively, trumpet sleeves style enhanced t stereoscopic and layered sense. Children's wear is orange hooded vest with 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 men's wear enhances the visual impact; the exaggerated curve of the overlap gives a fashionable atmosphere.

**Figure 2. Photos of prototypes**

*4.3.1. Four types performances of the interactive reaction*

When the distance between children and father decreases, the two garments, which are both C and A, produce a reaction respectively as ① mentioned above. 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 (Figure 3a).

When the distance between children and mother decreases, the two garments, which are both C and B, produce a reaction respectively as ② mentioned above. The manifestation is that the LED strips embedded in the hem of their garments start to shine at the same time (Figure 3c).

When child and parents are close to the set distance at the same time, the sleeves of the three wears shine simultaneously produce the change of ③ mentioned above (Figure 3d).

When father and mother stand together, the heart-shaped LEDs pattern in the chest of father's clothing and the LEDs pattern of mother's shoulder shiny simultaneously as the change ④ mentioned above (Figure 3b).

*4.3.2. Three types performances of one-piece clothing's self-reaction*

Father's clothing, its own reaction is triggered by the induction of photosensitive diode module, causing the front of the zipper part of the LED strips activated, to achieve the previous envisaged interactive effect ⑤ (Figure 3g).

Mother's clothing, the embedded LEDs is activated when collar buckled up, to achieve the expected interactive effect ⑥ (Figure 3e).

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 ⑦ (Figure 3f).

**Figure 3. Interactive effects of prototypes a-g (from left to right)**

According to the above various demonstration effects of these prototypes, embedding IoT technology could greatly enrich the design concept and manifestation of the parent-child clothing. These prototypes demonstrate some ways to apply the IoT technology expression form for the research aim of parent-child clothing, and confirmed the hypothesis 1 and the RQ 1 in the research aims.

## 5. Comparative evaluation and discussion

### 5.1. Selection of six categories comparative evaluation objects

Evaluation elements include Leisure style, Dress style, Graffiti style, Deconstruction style, National style and our prototype i.e. Optical sensing sci-fi style (Figure 4). These six categories could cover and represent the existing types of parent-child clothing on the market.


**Figure 4. Photos of comparative categories**

### 5.2. Selection of three categories semantic opposite adjective

We construct three categories of words total 24 pairs of antonym phrases, respectively selection from three-level concept of parent-child clothing, which was summarized by prior interview: the clothing style design, engineering technology, parental clothing extension meaning (Table 1).

**Table 1. 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 | Closed | Open | 24 | Enthusiastic | Indifferent |
| 7 | Fashionable | Outdated | 16 | Systematic | Messy | | | |
| 8 | Cross-border | Closed | 17 | Multifunctional | Single | | | |
| 9 | Concise | Tedious | 18 | Emotional | Rational | | | |

### 5.3. Participants' selection and evaluation requirements

Clothing industry personnel, information science and optoelectronics engineering personnel, children's parents. The reasons for choosing these three groups as participants are as follows: Clothing industry personnel, especially engaged in clothing design professionals, could compare clothing to make professional evaluation. Because the prototype of this experiment used information sensing technology and optoelectronic technology, therefore, it is hoped that the researchers of information science 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 the result will be more convincing with the help of the target users' evaluation.

We provided brief introductions to participants about the different contexts of the six categories evaluation elements. Then we ask participants according to their knowledge background and living habits to rating each of perceptions regarding these six categories parent-child clothes used semantic differential scales. For the evaluation scales, take pair item "Smart and Rigid" as example, we devided into 7 points from the most "Smart" level to the most "Rigid" level. Finally, 73 valid questionnaires were collected, the participants including 14 people engaged in the clothing industry, 23 information photoelectric technicians and 36 children's parents.

### 5.4. The difference between two categories of parent-child clothing

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

**Table 2. Results of paired-samples T-test**

| | | Mean | SD | SE | *t* | df | *p* |
|---|---|---|---|---|---|---|---|
| Rigid | Smart | 1.781 | 1.557 | .182 | **9.774** | 72 | .000 |
| Monotonous | Creative | .890 | 1.663 | .195 | 4.575 | 72 | .000 |
| Outdated | Fashionable | .027 | 1.624 | .190 | .144 | 72 | .886 |
| Closed | Cross-border | 1.411 | 1.373 | .161 | **8.782** | 72 | .000 |
| Vulgar | Elegant | -1.027 | 1.972 | .231 | **-4.452** | 72 | .000 |
| Tedious | Concise | -1.466 | 2.109 | .247 | **-5.939** | 72 | .000 |
| Destructive | Environmental | .178 | 1.743 | .204 | .873 | 72 | .386 |
| Bound | Flexible | 1.068 | 1.719 | .201 | 5.312 | 72 | .000 |
| Traditional | Technology | 1.781 | 1.669 | .195 | **9.118** | 72 | .000 |
| Isolated | Interactive | 1.192 | 1.560 | .183 | **6.526** | 72 | .000 |
| Open | Closed | -.137 | 2.057 | .241 | -.569 | 72 | .571 |
| Messy | Systematic | -1.082 | 2.228 | .261 | **-4.149** | 72 | .000 |
| Single | Multifunctional | 1.808 | 1.912 | .224 | **8.079** | 72 | .000 |
| Rational | Emotional | -.616 | 2.271 | .266 | -2.319 | 72 | .023 |
| Alienated | Affinity | .219 | 1.652 | .193 | 1.134 | 72 | .261 |
| Cold | Warm | -.603 | 1.614 | .189 | **-3.191** | 72 | .002 |
| Stodgy | Interesting | -.096 | 1.108 | .130 | -.740 | 72 | .462 |
| Disappointed | Surprise | .164 | 1.871 | .219 | .751 | 72 | .455 |
| Gloomy | Relaxed | -.192 | 1.883 | .220 | -.870 | 72 | .387 |
| Indifferent | Enthusiastic | .521 | 1.519 | .178 | 2.927 | 72 | .005 |
| Conservative | Avant-garde | .630 | 1.568 | .184 | 3.434 | 72 | .001 |
| Lively | Staid | -.397 | 2.559 | .300 | -1.326 | 72 | .189 |
| Rough | Exquisite | -.753 | 1.949 | .228 | **-3.302** | 72 | .001 |
| Mature | Childlike | .630 | 2.010 | .235 | 2.678 | 72 | .009 |

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.
According to results summary from paired-samples t test between prototype and traditional parent-child clothing (Table 2), 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 is significantly higher than that of the traditional parent-child clothing, which once again validates the H1 is valid.
However, it is also indicating that the H2 is cannot be confirmed, because compared with the traditional parent-child clothing, the weakness of the prototype is just the Elegant and Warm and other emotional extension elements. There is the most significant difference between the bold and underlined parts of the *t* value in Table 2. 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.
In order to continue to confirm the result, we have to add another estimate. We separately extracted the five semantic adjective items with the highest frequency value of above-mentioned two categories of clothing evaluation as the index of differential analysis. 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%). These are also the characteristics and advantages of prototype. While the advantage of the Dress style clothing are 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 married with the liberal arts and humanities that makes our hearts sing. For the emotional product of clothing, embedding IoT technology to achieve mutual interaction effect is relatively easy to achieve. Nevertheless, the results from our evaluation experiment show that the technology-oriented clothing is relatively cold and lacks humanistic emotion. Therefore, how to enhance the emotional value of smart parent-child clothing will be our next research goal response to Q2 mentioned above.

## 6. Deficiencies and future studies

The limitations of the comparative method of image observation and evaluation can 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, therefore, the follow-up study will adopt the evaluation method of participants' wearing experience test.

## 7. Conclusions

Through the prototype design and production, its final effect presents that introducing IoT technology can enrich the expressive form of parent-child clothing and expand the dimensions of design creativity. The booming application of IoT technology in the fashion industry has prompted us to start thinking about the integrated approach seriously between high-tech and emotional products. IoT is a typical representative of high technology, and parent-child clothing is the model of emotional products. We should seek more and better alternative ways to find out which type of high-tech is more suitable to the design and development of parent-child clothing, explore new elements of optimizing design, provides more practical approaches to realize the IoC cycle for the coming age of ubiquitous intelligent IoT applications.
In the evaluation experiment, the scale of the comparison between the prototype and the traditional parent-child clothing has inherently demonstrated the close relationship between humanistic emotion and advanced technology, validated the necessity of combining emotional design with high-tech

application. These two elements of IoT technology entities and emotional virtual bodies are indispensable in the future product development.

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Dr.-Ing. Weizhen Wang, Associate professor
Japan Advanced Institute of Science and Technology, Knowledge Science
1-1 Asahidai, Nomi, Ishikawa 923-1292 Japan
Email: s1620443@jaist.ac.jp