Interactive technology embedded in fashion emotional design
Case study on interactive clothing for couples

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Abstract
Purpose – The purpose of this paper 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 the IoT technology.

Design/methodology/approach – This 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 step in the design and production of prototype clothing, and do the initial emotional evaluation. The second experiment is the comparative evaluation of the prototype and other typical smart clothing.

Findings – The interactive clothing prototype was proven to correlate well with human emotional expressive patterns. The evaluation I indicated the prototype can 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.

Originality/value – This study builds the research and development theoretical model of interactive clothing that can be integrated into daily smart clothing life design, and analyze the methods and means of blending IoT smart information-sensing technology with emotional design. By means of this experimental demonstration of human-centered interactive clothing design, the authors provide smart clothing 3.0 evolutionary roadmap and propose a new concept of internet of clothes (IoC) for further research reference.

Keywords Emotional expression, Interactive technology, Fashion design, Human-centered, Smart clothing

Paper type Research paper

1. Introduction
Technology is changing our lifestyles. As daily necessities of human life, clothing, especially fashion clothing lifestyle, carries the increasing physical and social properties. Following the further development of internet of things (IoT), smart clothing

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is a key component of IoT revolution into daily life, while advanced sensor interfaces constitute compelling new technology that is rapidly being disseminated. Considerable interest is being generated by the remarkable functions of carefully crafted (Barfield, 2015; Gilsoo, 2010), the development of smart clothing in daily life has aroused more attention.

In the fashion industry, incorporating technology for many brands was streaming their shows in the Spring Summer 2016 Paris Fashion Week (SS16, PFW). These brands have come to accept that without fashion their design ideas technically will not succeed in wooing consumers. We can take ANREALAGE as a typical representative. This fashion brand opted for a personalized AR functionality experience crosses paths between technicity and beauty, in SS16 PFW and SS17 TFW (Tokyo). Their designers teamed up with the computer programmer to create a series of black-and-gray fabric patterns mimicking the visual static from analog TVs, when models who were wearing clothing use of photosensitive fabrics approached the walls or iPads, thanks to visual cryptography, the patterns occasionally flickered or changed from checkered to floral motifs. The AR technology, rendering the atmosphere of the fashion show, contributes to form 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.

In academia, as early as a decade ago, researchers have begun to systematically explore the main development direction of smart clothing in the future (Cho et al., 2009; Suh et al., 2010; Ariyatum et al., 2005; Tao, 2005). 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; Schull, 2016; Perovich et al., 2014; Wright and Keith, 2014; Yu et al., 2014). However, the imbalanced contribution from electronics and fashion industries is very obvious, this is due to the current smart clothing design model which has not yet matured (Ariyatum and Holland, 2003). Some researchers may have ignored the fact that clothing has interactive zymology in the context of sociology (Crane, 2001), and that clothing possesses properties of implied emotional interactive expression (Norman, 2004; Jones, 2005). As Prof. Hiroshi Ishii from MIT proposed in the lecture of 2016 Symposium on System Integration, technology soon becomes obsolete but true visions can last longer, art and philosophy, design and technology, art and aesthetics all should be coordinated development.

Given that art aesthetics and emotion are more important elements of design than technology in the field of fashion design, in this research, we focus on case design optimization of the couple clothing from the perspective of humanities and technology synergistic development. It will effectively present a methodology for combining emotional elements, fashion elements and interactive elements, as well as the embedded IoT technology in exploring the diversity of interactive forms for interactive clothing, with realistic theoretical and applied research significance. The paper structures as follows: first, to define the attributes of clothing in the future IoT by the classification, induction and deduction of literature. Followed by the aims and hypotheses, we designed and produced a series of prototypes. Finally, the kansei evaluation approach and results are presented, concludes with discussion and conclusion section.

2. Related work and definition

2.1 The physical and social properties of clothing

The research of product development or the deduction of its future development cannot be separated from the product’s past and current essential attributes and its development law. From the physical level to the spiritual level of humanistic and technical perspectives,
the related research literatures are classified for the logical analogy. As a necessity of human life, clothing has six-dimensional essential properties, as shown in Figure 1:

1. providing modesty and protection (Dunlap, 1928; Kittler et al., 2003);
2. improving warmth and comfort (Pedersen, 1923; Toups et al., 2010);
3. displaying logos (Harms, 1938; Gilligan, 2010);
4. reflecting a certain level of technological development (Twigg, 2009; Park et al., 2014);
5. conveying certain social and cultural connotations (Harms, 1938; Feinberg et al., 1992; Lennon and Davis, 1989a, b); and
6. facilitating communication and expression (Norman, 2004; Kaiser, 1983; Hsu and Burns, 2002).

- I – Physical and Sociological properties of clothing: the above six properties can be classified as three grades of physical ((1) (2) and (3)), social ((4) and (5)) and spiritual properties (6).
- II – Grades of clothing property according to Maslow’s Hierarchy of needs (Maslow, 2013): physical properties are also basic properties include ((1) (2) and (3)). Sociological properties include ((4) (6) and (6)). Among them (4) and (5) belong to intermediate properties, and (6) belongs to advanced property (Flugel and Fago, 1933; Pedersen, 1923).
- III – The technical properties are mainly combined with smart technology to achieve the technical functions of clothing. Each individual’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 1, III): traditional 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)).

**Figure 1.** The interrelationships between properties of clothing and their evolutionary path

**Notes:** (I) Types of clothing property; (II) grades of clothing property; (III) technical grades of functioning clothing property
Smart clothing is distinct from wearable computers in that smart clothing is essentially a kind of clothing, rather than a computer or an independent, smart technology platform. Smart clothing cannot be separated from the original properties of traditional clothing (Barfield et al., 2015). With improved quality of life, individuals tend to focus on emotional well-being and social interaction. Clothing is one symbolic medium allowing individuals to communicate with the outside world (Baurley, 2004; Hsu and Burns, 2002; Kaiser, 1996; Barthes, 1968/1983; Jones, 2005).

2.2 The difference between interactive clothing and smart clothes
Gepperth (2012) separated the application scenarios of wearable computing into three categories: “Sensing and data analysis,” “Interfaces” and “Functionality and Aesthetics.” We are using this category of IoT functionality and design aesthetics to definite interactive clothing.

Interactive clothing with the characteristics of fashion, one branch of smart clothes, emphasizes more on the characteristics of the clothing network with the 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)).

3. Aims of study
The aim of this study is to bridge the gap between human emotions and wearable technologies, to consider human-centered design factors for the design of interactive clothing, according to soft system methodology, i.e., the “WHY,” “HOW” and “WHAT,” as shown in Figure 2. WHY: this factor investigates the reasons why smart clothing should satisfy technical functions and human emotional expression simultaneously. HOW: this factor investigates the manner in which artistic design perspectives and engineering methods can be effectively combined, blending emotion with smart technology in the form of interactive fashion innovation. WHAT: this factor refers to the R&D elements of future smart clothing based on the IoT technology. Interactive clothing for couples was selected as a representative example as explained below. Using these three design factors, a prototype design is developed for the given case study and the kansei evaluation method is employed, constituting an experimental demonstration of a futuristic human-centered interactive clothing design.

4. Hypotheses and methodology
4.1 Hypotheses
With the unremitting efforts of researchers, we have preliminarily realized the function of making the clothing become smart. However, in the realization of technological progress,

![Figure 2. Design factors for smart clothing R&D direction](image-url)
it is necessary to explore the possibility of integrating smart clothing into the daily life of consumers and the future IoT 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 (Mana et al., 2016; Jagelka et al., 2016). However, the development of multiple items 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 main emotional responses of the body can be reflected through this relationship. Because clothing has a metaphysical attribute, smart clothing can reflect the relationship such as happiness, anger, sadness and joy between wearers. Baurley (2004) proposed that people can interact with the clothing of others nearby by changing the visual appearance. In the design process, Schütte (2005) contributed to balance between functional technology and emotional expressiveness:

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 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 Methodology
This study combines artistic design perspectives with information-sensing engineering methods as well as kansei evaluation method.

The methodology of prototype design 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 second methodology is kansei engineering (Rajasekera and Karunasena, 2015). This experiment is divided into two steps. The first step is the initial emotional evaluation for the prototype. The second step is the comparative evaluation of the prototype and other typical smart clothing.

5. Prototype experimental approach
5.1 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 by 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 5 R (Reduce, Reevaluate, Reuse, Recycle, Rescue) design goal (Wang et al., 2014).
The prototype design styles are shown in Figure 3 (labeled a-d for future reference). Among them, “a” and “b” are two women’s styles, “c” and “d” are couple styles. The main pattern and size are shown in Table I and Figure 4.

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 or a good friend with a close relationship (not for random people or co-workers) as prototype target user of interactive clothing design.

From the psychological point of view (King-O’Riain, 2016), distance can also represent the intimate or estranged relationship between two people. Therefore, we decided to use distance as a trigger for the interaction, and embed the sensor into the clothing. In order to

![Figure 3. Clothing designs, labeled a-d (from left to right)](image)

<table>
<thead>
<tr>
<th>Position</th>
<th>Style a</th>
<th>Style b</th>
<th>Style c</th>
<th>Style d</th>
</tr>
</thead>
<tbody>
<tr>
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<td>170/88</td>
<td>170/88</td>
<td>175/92</td>
</tr>
<tr>
<td>Bust</td>
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<td>88 + 10</td>
<td>88 + 12</td>
<td>92 + 16</td>
</tr>
<tr>
<td>Front width</td>
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<td>17.2</td>
<td>18.5</td>
<td>21</td>
</tr>
<tr>
<td>Back width</td>
<td>21.5</td>
<td>18.2</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>Armhole depth</td>
<td>21.5</td>
<td>21.5</td>
<td>20.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Back neck drop</td>
<td>9.6</td>
<td>9</td>
<td>8.4</td>
<td>9.6</td>
</tr>
<tr>
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<td>12.8</td>
<td>12.2</td>
<td>14</td>
</tr>
<tr>
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<td>60</td>
<td>65</td>
</tr>
<tr>
<td>Front length</td>
<td>43</td>
<td>48</td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td>Neck waist length</td>
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<td>38</td>
<td>38</td>
<td>43</td>
</tr>
<tr>
<td>Sleeve length</td>
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<td>57.5</td>
<td>45</td>
<td>58</td>
</tr>
<tr>
<td>Sleeve opening</td>
<td>25</td>
<td>24</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>

**Note:** Unit: cm

**Table I.**

Pattern size
Figure 4.
Pattern of style a-d
(from top to bottom)

Note: The sleeves of pattern (b) and (c) are ignored.
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; Leonard, 2017; Stylios and Yang, 2013).

5.2 Material selection

Clothing outer fabric and liner filler material. Transparent material is the material of choice for the 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 bend 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, five to eight 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 and serial communication. Considering the compatibility of traditional code programs and the operating speed, we also employed an 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 8,501 instruction code. A mic-transformer was also required, in order 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.

Electronic embedding design. Take style a as example, the power supply, single-chip (1) and sensors (2) embedded in the back center seam of the clothing, using insulated wire hidden in the hem and side seams (3) (Figure 5). The schematic circuit design which takes five LEDs as example can be seen in Figure 6. US100 as the main creative medium, and using single-chip programing process to control the LEDs brightness changes. The entire circuit access voltage is 12 V, US100 operating voltage DC 2.4-5.5 V, STC12C5A60S2 operating voltage is 3.3 V, so the circuit also needs to add a transformer. The above materials and the kansei evaluation described below corresponds to the “WHAT” design factor presented above.

![Figure 5. Electronic embedding design (style a)](image-url)
5.3 The final effect of the prototype

The prototype is realizing interaction between two clothing items. The interactive clothing was proven to correlate well with human emotional, expressive patterns (Figure 7). 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 7, styles “a” and “b” two items clothing together are girlfriends clothing style, and “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. Style “b-1” is the effect of style “b” activated sensor; “b-2” is the effect of the dark environment. Styles “c” and “d” two items clothing together are lover couple style, and “d-1” is a close-up of the vertical bar-shaped LED effect in the front chest position.

6. Kansei evaluation and discussion

6.1 Kansei evaluation I

We used the semantic differential method to analyze the effects of the interactive clothing on the psychological responses of wearers. Several emotion models exist. For example, Larsen and Diener (1992) 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. For the evaluation scales, take item “joy” as example, we divided “joy” into ten points from the lowest level of “joy” to the highest level.

We conducted an emotional survey evaluation experiment under activate 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 couples college students participated in this wearing experiments. In total, 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 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.

The survey data for the active and non-interactive clothing differed significantly. In the case of the inactivate range for the LED sensor, eight-way split model Figure 8(a) shows that the main range of the evaluation index fluctuation is within 6. However, for the activate range of the LED sensor, Figure 8(b) 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 II. 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 $H2$ are validated. This also corresponds to the first design factor “WHY” introduced above.

![Figure 8](image_url)

**Figure 8.** Results of kansei evaluation of 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
6.2 Kansei evaluation II

After completing the emotional value evaluation, follow-up comparative evaluation experiment is continued. Experimental form: multi-category smart clothing comparative evaluation. 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.

Evaluation subject: it includes college students who have participated in previous experiments, including design disciplinary (as a designer cluster), information engineering disciplinary (as an engineer cluster) and other disciplines (as consumer cluster) of the three clusters, each of six 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 inviting them to participate in the second experiment was conducive to the continuity of the experiment.

Evaluation object: prototype, ANREALAGE (above-mentioned brand), smart sportswear (De Acutis and De Rossi, 2017), healthcare clothing (Chen et al., 2017):

Annotation of compare objects.

The prototype and ANREALAGE have mentioned above.

Ralph Lauren OMsignal Polo Tech shirt is typical smart sportswear. It is the first luxury sport 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.

Wearable 2.0 healthcare system, 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.

Evaluation words: functional, practical, futuristic, emotional transmission, appearance style, interactive technology.

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.

Overall, Figure 9 shows that the average score of the prototype is significantly higher than other three types of smart clothing in the three clusters's evaluation of these four types 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 10 uncoveres designer cluster and shows that the best points of the prototype are future-style, emotional and interactive; the most vulnerable is the functional. Figure 11 reveals the engineers’ view that the prototype’s best points are future-style and emotional, the weakest point being functional. Figure 12 shows that consumer cluster thinks that the best point of the prototype is future-style, the most vulnerable are functional and practical.

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-interactive</td>
<td>4.00</td>
<td>5.26</td>
<td>5.59</td>
<td>5.47</td>
<td>4.47</td>
<td>3.50</td>
<td>2.91</td>
<td>1.29</td>
</tr>
<tr>
<td>Interactive</td>
<td>5.09</td>
<td>7.82</td>
<td>6.85</td>
<td>8.29</td>
<td>5.62</td>
<td>3.94</td>
<td>3.35</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Note: Average emotion values for interactive and non-interactive, for the eight-way split model
Comprehensive evaluation of different groups shows that people’s expectations of the future of smart clothing are not just focus 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 needs to be improved. We can see that the design concept of implanting wearable technology in clothing improves the function of garments, which is not yet a widespread resonance among consumers. Only on the basis of 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.

![Figure 9. Comparison of average values by designer, information engineer and ordinary consumer clusters](image)

![Figure 10. The evaluation value of designer cluster to four kinds of smart clothing](image)

![Figure 11. The evaluation value of information engineer cluster to four kinds of smart clothing](image)
6.3 The revelation of prototype to future product development

Embedding smart technology into clothing for “HOW, WHAT” element and H2 mentioned above. Our experimental prototype was produced using widely available electronic components that were simply inserted into the clothing. However, it can still realize the effect of the IoT technology on the interaction between clothes. IoT allows objects in the environment to become active participants in communication, i.e., they share information with other stakeholders of a network.

From an evolutionary perspective, smart clothing has obvious potential applications. The future development of this field can be divided into three evolution stages (Figure 13).

1. 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 (Mana et al., 2016; Jagelka et al., 2016), these fruitful studies belong to the Stage 1.0 of the evolution of smart clothing. In addition, the interactive feedback of new fabrics on the human body data is developed through the biological gene angle (Wang et al., 2017), as well as Tangible Media Group of MIT presented the bio is the new interface, which belongs to another research perspective, not to study the use of the IoT technology for the human body information feedback, so it is not within the scope of this paper.

2. 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.

3. 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 series of clothing, thus allowing the formation of a clothing network. That is, Stage 3.0 is the internet of clothes (IoC) formed on the basis of the IoT technology platform. Through the Stage 3.0 of smart clothing, people can connect the virtual network and the reality 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.

![Figure 12. The evaluation value of ordinary consumer cluster to four kinds of smart clothing](image)

![Figure 13. Roadmap of smart clothing evolution to interactive](image)
Both the Stages 2.0 and 3.0 evolved from the Stage 1.0 characterized by the response of clothing to the human body, which evolution corresponds to a technical extension. The prototypes examined in this study belong to stage smart 2.0 clothing products. Further challenges and opportunities will be encountered when achieving stage smart 3.0, as a clothing network is the future research vision. This also corresponds to the second design factor “WHAT” introduced above.

Considerable effort from both industry and academia has been devoted to the development of wearable technology and intelligent textiles. In academia, previously research mainly focused on smart clothing Stage 1.0 with basic intelligence features. Currently, we should turn our attention to smart 2.0 research on interactive clothing; further research objective is to achieve advanced 3.0 levels of interactive clothing in the future. Although much of the technology employed in this research field is not yet mature, being inconvenient or uncomfortable for the wearer, and only a small number of products have been introduced to the market. However, interactive clothing with advanced and compelling information-sensing technology will be rapidly disseminated once designers achieve remarkable functionality and carefully crafted products.

**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 vividly express the wearer’s emotions. 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 important 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). Further, Giacomin (2014) 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.

As shown in Figure 14, we should further investigate the structure of the emotions underlying human clothing-related behavior, to obtain a more inclusive vision of the social

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**Figure 14.** Human-centered R&D process for interactive clothing
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.

7. Limitations and further research
The sensors combined with LED display technologies are a relatively mature technology, the use of this technology in prototype design simply for the convenience and easiness to achieve the 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 course of the experiment, the participants’ wearing experience time is limited, and the evaluation is mainly subjective.

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.

8. Conclusions
In this study, interactive clothing for couples was examined using experimental prototypes. The efficacy of this clothing was then assessed using a kansei evaluation. Hence, the prototypes were proven to correlate well with human emotional, expressive patterns and satisfied the research hypotheses.

This study builds the research and development theoretical model of interactive clothing that can be integrated into daily smart clothing life design, and analyzes the methods and means of blending IoT smart information-sensing technology with emotional design. By means of this experimental demonstration of human-centered interactive clothing design, it provides smart clothing 3.0 evolutionary roadmap and proposes a new concept of IoC for further research reference.

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.

References


Further reading


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