CREATION OF INTERACTIVE FASHION

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Creation of Interactive Fashion

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

XIA Wenjing

To my parents and my love

ABSTRACT

In a dynamic and ever-changing world today, any immutable fashion norm is being overtaken by a surge of searching for new, dynamic clothing models. At present, the prevailing concept of clothing is one that clothing is perceived often as static and mortal. A piece of clothing item is 'active' only when it is activated by the movement of the wearer while it is being worn. Nevertheless, this kind of actions and/or changes is unilateral, initiated but by the wearer. Scare past attempts have been made to expand and invent fashion that go beyond this unilateral 'action' to becoming 'interactive'. It is the ultimate aim of this research to expand, invent and create fashion clothing that are interactive between the clothing and the wearer and/or between the clothing and the context in which it is worn by which the role and values of fashion are redefined.

Ever since Interactive Art was presented in 1960s, interactivity has been increasingly popular, notable in designs from sophisticated industrial products to daily household appliances. With the rapid development in computing science and electronics, human-artifact interactivity has been made possible. Very often, interaction designs today adopt electronic technology terms and user interface designs. While modern living has been increasingly interactive, equal attention has been drawn upon emotion psychology in the course of interactions. It is timely indeed for the aspiration for creation of Interactive Fashion (IF) and a deeper understanding of its interactions among wearers and between wearer and clothing.

In this study, an original theoretical framework of interactivity which is standardized, systematic, and multifarious was established through a study of substantial amount of prior representative works of interactivity. The framework provided theoretical reference for decoding and analyzing interaction design applications whereby various interaction

processes, interactive relations and levels were summarized towards a better understanding of the essence and law of the happening of interactivity as well as their varied courses. An original theoretical system of IF based on the said theoretical framework was further established to elucidate the interaction processes, interactive relations and levels peculiar to interactivity in fashion. In analysing the operational system of interactivity, references were made to the said theoretical framework of interactivity against various specific exercises of interactivity. Meanwhile, the theoretical system of IF helped guide the designs and creations of IF towards the latter stage of this study when the emphasis turned to focusing more on analyzing IF that detects and recognises emotional changes based on physiological data measurement obtained via visual expression observed, during which interactions between prototypes of IF created, i.e., 'Breathing Dress' and 'Heartthrob Dress', and human were studied in the light of the theories of emotional recognition and physiological signal data measurement for emotional recognition. Since the convention of emotion recognition based on physiological data has been but a relatively simplex statistical summary of the various collected physiological data in a hope that relationship between emotional changes with any particular data from a broad perspective can be discovered, this research added on to this foundation concept of emotion recognition a concept of data synthesis and organization from related sensors towards an advanced and more accurate emotion recognition and understanding. The knowledge gained shed light on an in-depth theoretical and operational understanding of the interactivity among IF and human.

All along, the research method made close reference to contemporary fashion trends, new design ideologies, and leading examples of interactive art and design. In addition to advance the holistic and deeper understanding of emotion, combining modern design features, appropriate materials, and the technological development in electrics and electronics, this research created a holistic concept of interactive clothing that are both structurally innovative and functionally sophisticated, whereby clothing is escalated to a new level where they are not only fashionable and comfortable to be wore, but also can they suggest real-time moods and emotions of the wearers for timely responses (e.g., comforted (when feeling sad), praised (when having success), enlightened (when being bewildered), etc.). Ultimately, the study activated clothing we wear – an everyday item that has an intimate relationship with our life. Since clothing are commodities so closely associated with our daily activities, the simultaneous interaction between clothing, wearers and surrounding/spectators through interactive physiological detection and visual responses advance understanding of emotion recognition. Such understanding and recognition are no doubt of tremendous value contributive to the long-term development of emotion management and medical/physiological diagnosis. Successful creation of Interactive Fashion not only expanded the aesthetical and technological dimensions of fashion attributive to the subsequent redefinitions of fashion as *object d'art* as well as utility, of humanities and technology, but also did it reshape our lifestyle and cultural context in which we live.

PUBLICATIONS ARISING FROM THE THESIS

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- XIA, W.J. and NG, M.C.F., A Study of Interactivity in Art and Design, Research Journal of Textile and Apparel. Vol. 15, No. 3, August 2011, pp.139-143.

(CONFERENCE PAPERS)

- NG, M.C.F. and XIA, W.J., A Study of the Communication System of Interaction Designs, CCCT08 (International Conference on Computing, Communications and Control Technologies), Florida, USA, 29 Jun. - 2 Jul., 2008.
- NG, M.C.F. and XIA, W.J., A Study of Interactive Effect in Interactive Fashion (IF), invited paper at the 11th Asia Textile Conference "Knowledge Convergence in Textiles for Human & Nature" held at EXCO, Daegu, Korea, 104 November, 2011, Korea. In print.

(AWARDS AND EXHIBITIONS)

- XIA, W. J., "The Outstanding Award", Arts of Fashion 2008 Student Design Competition, Arts of Fashion Foundation, USA. October 2008.
- XIA, W.J. and NG, M.C.F., "Bronze Award" of the International Women's Wear Design Contest of the 2008 China Cup International Fashion Design Contest. Shanghai, China. April 2008.
- XIA, W.J. and NG, M.C.F., "The Best Ten Award", International Women's Wear Design Contest of the 2008 China Cup International Fashion Design Contest. Shanghai, China. April 2008.

(PATENT)

- XIA, W.J. and NG, M.C.F. The Emotional Interactive Fashion (情绪互动服装) (Patent Registration Number: 201020561808.4), 14 October 2010, China.

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LIST OF ABBREVIATIONS AND INDEXES

Abbreviation of Terms	Meaning
ADC	Analog-to-digital Converter
AGND	Analog grond
AIN	Analog input
BVP	Blood volume pulse
C	Communicative
CAD	Computer-aided design
ECG	Electrocardiosignal
EDA	Electronic design automation
EEG	Electroencephalography
EMG	Electromyography
Hu	Human
I	Interactive
IA	Interactive Artifact
IAP	Interactive Artifact Program
IF	Interactive Fashion
LED	Light-emitting diode
MCU	Micro-controller unit
MEMS	Micro Electro Mechanical Systems
N	Non-interactive
OLED	Organic light-emitting diode
PCB	Printed circuit board
R	Reactive
RSP	Respiration
SC	Skin conductivity
SCM	Singlechip machine
SKT	Skin temperature
SoC	System on Chip

CHATPER 1

INTRODUCITON

1.1 Research Background

In a dynamic and ever-changing world today, any immutable fashion norm is being overtaken by a surge of searching for new, dynamic clothing models. At present, the prevailing concept of clothing is one that clothing is perceived often as static and mortal. A piece of clothing item is 'active' only when it is activated by the movement of the wearer while it is being worn. Nevertheless, this kind of actions and/or changes is unilateral, initiated but by the wearer. Scare past attempts have been made to expand and invent fashion that go beyond this unilateral 'action' to becoming 'interactive' (Interaction is broadly defined as presence of interdependent actions at the mutual initiation between two or among more subjects). Thus, it the aim of this research to expand, invent and create fashion clothing that are interactive between the clothing and the wearer and/or between the clothing and the context in which it is worn, i.e., Interactive Fashion (IF).

'Interactivity', as the origin of this research, was first expressed in art as early as the 60s (Chris, 2003), and it started to develop into various design disciplines such as installation, architecture, product, as well as fashion and textiles since 1980s (Dan, 2006). Today, our life is increasingly interactive.

Interactivity is broadly divided into three levels: non-interactive, reactive and interactive. With the development of computer science and digital technology, multimedia technologies have been incorporated into artwork which gave rise to new art forms, i.e., New Media Art

(Michael, 2005). Being the main characteristic of new media art, Interactivity detached and developed into a medium of new art form – Interactive Art (Lev, M., 2002). Since electronic products and user experience needs were becoming complicated, Interactivity has become a design form to create dialogues between human and artifact (Helen, Yvonne and Jenny, 2007). The term 'Interaction Design' was first proposed by Bill Moggridge and Bill Verplank in the late 1980s.

Since the happening of Interactivity has a close inter-relationship with electronic design. Electronic design technology is the based technology for setting up interaction processes and operating the whole system of interactive fashion. Electronics technology related to the research includes the following three areas: electronic design automation (EDA) technology, microelectronic technology, and embedded system design. The development of electronic technology, including that of computer technology and digital technology, has brought revolutionary impact and excitement to traditional art, design and fashion and has generated many new areas, such as computer art, digital design, smart product design, digital print for fabric, wearable electronics and so on. The designing of wearable electronics involves the use of some computerized devices or electronic devices that are well designed in the clothing materials worn by people (William and Alberto, 2009). The earliest wearable electronics can be traced back to the 'wearable computer' appeared in 1960s. With the rapid development of science and technology, wearable electronics has exceeded a great number of limitations of existing technologies and has become a hot topic in cross-disciplinary research and application. Nowadays, wearable electronics can be applied to smart fabrics, wearable e-textiles, intelligent clothing and smart fashion. Over the past few years, many textile scientists and electronic engineers have been conducting research on various technologies of textiles and clothing related to interactivity. Besides research on functionality, a few fashion designers also started to design interactive intelligent clothing and smart fashion (Chalayan, 2007).

Over the past few decades, there has been increased emphasis on research on emotion. Emotion has become a branch of psychology in its own right. It has its own niche in sociology, retailing, computing, design, etc. In the research area of human-computer interaction in particular, the computer too recognizes emotion to meet people's spiritual needs. This capability ultimately enables computers to naturally and vividly interact with humans, like humans do (Rosalind, 2000). Humans' psychological needs will eventually return to the simplest level, while computers with emotional intelligence can be the media for transformation and realization. Creation of IF is also based on these concepts of human-computer interaction, focus on emotional recognition to help people to ultimately achieve interactive communication among them.

1.2 Research Aim and Objectives

It was the ultimate aim of this study to expand, invent and create new concept fashion that is interactive between the clothing and the wearer and the context in which it is worn by which the role and values of fashion are redefined. Specific objectives of the study were to:

- acquire an understanding of the concept and development of Interactivity in art and design which are the original background of this research;
- study and understand the basic emotion psychology related to human interaction;
- establish a theoretical framework of Interactivity and a independent theoretical system of IF in the context of design, technology, psychology and humanity;
- study and identify potential technologies, materials and structures for creation of IF;
- experiment with and invent new forms of IF via deployment of electronic technologies, materials and structures toward a novel form of visual art and communication;
- design and create IF prototypes;
- study the interactivity through the interactions between the IF prototypes and human;
- expand the visual dimension and content of fashion across art, design, technology, psychology and humanities; and to
- disseminate the findings in both literal and product forms.

It was envisaged that the successful creation of IF would expand the invent visual dimensions of fashion which in turn, attributive to the ultimate re-definition of art (fashion), humanities and technology by which our culture and lifestyle are re-shaped, and would further enhance research in this area.

1.3 Research Methodology

Research on IF is by nature interdisciplinary. It involves art, design, fashion, electronic technology, psychology, humanity, etc. Therefore, comprehensive literature review, systematic theoretical research, in-depth practical research as well as a series of integrated creations and applications were conducted. The detailed stepwise procedure of the study is summarized in Figure 1-1. In the initial stage, a comprehensive literature review was conducted for background research. It involved basic study of Interactivity in art and design, review of applications in various art and design disciplines, basic study of electronic technology, understanding of wearable electronics development and a general background study of emotion psychology on human interaction. In the second stage, a systematic theoretical research was presented. It includes establishment of theoretical framework of Interactivity, establishment of independent theoretical system of IF based on the theoretical framework on Interactivity, study of theory of emotional recognition via physiological signal data towards IF, with particular focus on investigation of physiological signal data measurement for emotional recognition. In the third stage, an in-depth practical research was conducted. After an appraisal and selection to identify the key elements on creation of IF, the emphasis shifted to explorations and experimentations of electronics on IF, materials and design methods on visual display as well as exploration of design aesthetics of the whole effect of IF. The fourth stage of the research focused on the creations of IF when the 'Breathing Dress' and 'Heartthrob Dress' were designed and produced. In addition, further tests were conducted to measure the interaction effect of creations and obtain the try-on feedbacks and information for future research. Finally, in the last stage, the research was concluded with the limitations identified and future work suggested.

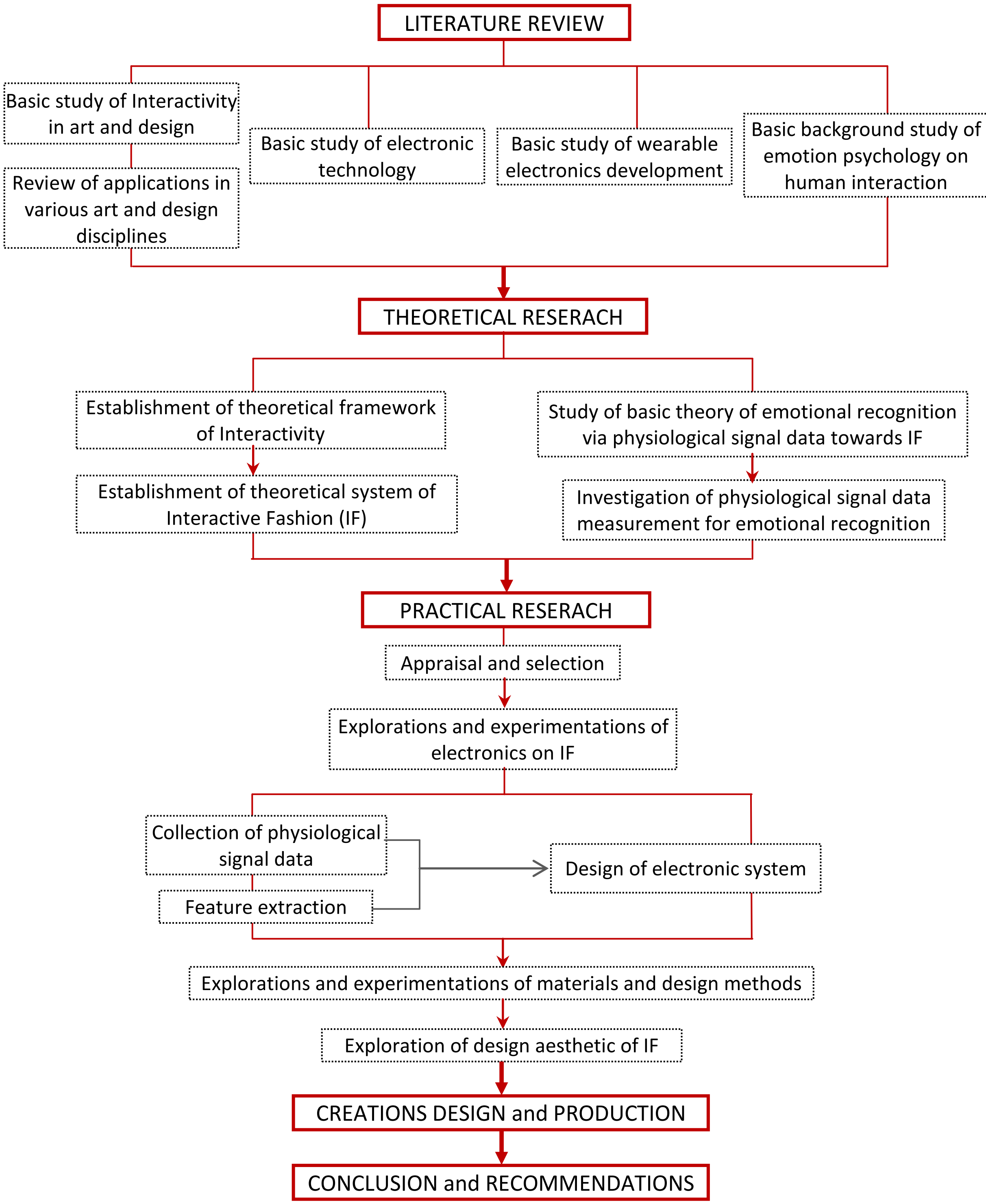


Figure 1-1. The stepwise procedure of the research.

1.4 Research Significance and Values

This research expanded, invented and created concept fashion that is interactive between the clothing and the wearer and the context in which it is worn. Since the research is an interdisciplinary integration which involved art, design, fashion, electronic technology, physiology, psychology and humanity, a study of substantial amount of prior applications of interactivity that include areas other than fashion was conducted by which an original theoretical framework of interactivity which is standardized, systematic, and multifarious was established. This theoretical framework of interactivity provided theoretical reference for decoding and analyzing interaction design applications whereby various interaction processes, interactive relations and levels were summarized towards a better understanding of the essence and law of the happening of interactivity as well as their varied courses. Based on the said theoretical framework of Interactivity, an original theoretical system of IF was further established to elucidate the interaction processes, interactive relations and levels peculiar to interactivity in fashion which helped guide the designs and creations of IF toward the latter stage of the research. The practical research started with the identification and appraisal of the key creation elements. Its emphasis shifted to focusing on emotional recognition for creation of IF which could detect and recognise emotional changes as well as to interact with wear via visual expression. Two creations, namely 'Breathing Dress' and 'Heartthrob Dress' were designed and produced. They advanced a holistic concept of IF that are both structurally innovative and functionally sophisticated, whereby clothing is escalated to a new level where they are not only fashionable and comfortable to be wore, but also can they suggest real-time moods and emotions of the wearers for timely responses and create subtle interactive effects among people. Meanwhile, its innovativeness causes the wearer to address his breathing and heartbeat irregularities through a strong visual display that presents real-time status, enabling the wearer to turn his attention to the necessary remedial action, and create subtle human-clothing interactions. Besides, visual information transmitted by IF allows spectators to roughly understand the current physical activity of a wearer as well as the fundamental emotional state, and thus can act on the interactions between the spectator and the wearer. It follows that the research of IF creative design is not merely on the surface of interactive technology or fashion design, but able to be used to promote a healthy life attitude – shifting the excessive attention from the external world to the humans' own inner world.

Successful creation of IF not only expanded the aesthetical and technological dimensions of fashion attributive to the subsequent redefinitions of fashion as *object d'art* as well as utility, of humanities and technology, but also did it reshape our lifestyle and cultural context in which we live. Successful accomplishment of the set objectives further enhanced research in this area whose results are of tremendous artistic and commercial significance and value.

1.5 Organization of Thesis

Chapter One is 'Introduction'. It presents the broad outline of the research, such as general research background, aim and objectives, corresponding research methodology, significances and values of the research, as well as a detailed organization of the thesis structure.

Chapter Two is 'Literature Review'. It deliberates the research background which includes basic definition of 'Interactivity', an overview of 'Interactive Art' and 'Interaction Design', a review of a large amount of application cases related to Interactivity in art and design (i.e., installations, architectures and products), introduction of electronic technologies related to IF, description of current development status of wearable electronics and introduction of emotion psychology on human interaction in social life.

Chapter Three is 'Theoretical Research'. It introduces the theoretical framework of 'Interactivity' and an independent theoretical system of IF established in detail as well as the theoretical basis of emotional recognition via physiological signal data towards IF which includes definition of emotion, identification of model of emotional recognition classification and investigation of physiological signal data measurement for emotional recognition is also introduced.

Chapter Four is 'Practical Research'. It presents the appraisal and selection of the key creation elements and design requirements of IF for the following research. In explorations and experimentations of electronics on IF, it presents the experiment of collection and feature extraction of physiological signals data, i.e., respiration (RSP) and blood volume pulse/electrocardiosignal (BVP/ECG), for setting up a model of emotional recognition classification. The real electronic system circuits have been designed and presented, including hardware, software and LED program design. In explorations and experimentations of materials and design methods of LED display, various combinations of materials and LED were tested and certain uncommon design methods of LED display were experimented and identified. It also presents the analysis of the design aesthetics of overall effect of IF.

Chapter Five is 'Creations'. It unfolds the design and production process of creation of IF as well as the final outcomes of the work. It also reports on the following tests conducted after the creation for testing the effects of interaction and obtain the feedbacks and further data.

Chapter Six is 'Conclusion and Recommendations'. It summarizes the main findings and overall conclusion of investigative work in the research. Furthermore, this final chapter also identifies the remaining problems and makes recommendations for further research works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Interactive Fashion (IF) is by nature interdisciplinary, having characteristics of diversification and complexity. Therefore, literature review has to consider a wide range of viewpoints. This chapter starts with description of art and design elements of the concept of interdisciplinary activities. The meaning of "interactivity", including the basic definition of "interactivity", has been explained. An overview of applications of interactivity in the area of art, and of interaction design is provided. The second part focuses on comprehensive review of examples of application and development of interactivity in art and design areas, including installation art, architecture and product design. Since IF is related to electronic technology discipline, the third part contains review of IF-related electronic technologies, including development status of relevant electronic technologies, and outlines the profound impact of electronic technology on art, design and fashion. As IF is a developing branch of wearable electronics, the fourth part introduces wearable electronics which combine electronic science and technology with fashion and textile design. The current status of development of wearable electronics is outlined and reviewed, including the latest applications of intelligent clothing and smart fashion. The focus is on understanding of interactivity performance in the current collection of intelligent clothing and smart fashion designs. The fifth part is to help understand the interaction actuality faced by people in today's society from the viewpoint of emotion psychology with which the research background of human values and social values of IF is contextualized.

2.2 Introduction of Interactivity in Art and Design

Before experimentation for creation of Interactive Fashion, a comprehensive review of the development and applications of interactivity in various disciplines of art and design is essential. Extant literature has reported that interactivity was first expressed in art as early as the 1960s (Chris, 2003), and it started to develop into various design disciplines such as installation, architecture, product, as well as fashion and textiles since the 1980s (Dan, 2006).

2.2.1 Definition of interactivity

Interactivity is similar to the degree of responsiveness, and is examined as a communication process in which each message is related to previously exchanged messages, and to the relationship of those messages to messages preceding them (Liu and J., 2002). In the 'contingency view' of interactivity, it is divided into three levels: non-interactive, when a message is not related to previous messages; reactive, when a message is related only to the last message; and interactive, when a message is related to a number of previous messages and to the relationships between them (2002).

Interactivity generally takes effect in human to human and human to artifact communication. Human to human interactivity is the communication between people and people whereas human to artifact interactivity is the way people communicate through new media (Rada, 1996). Here, interactivity refers to the artifact's interactive behavior as experienced by the human user.

2.2.2 Interactivity in Art – Interactive Art

With the development of computer science and digital technology, multimedia technologies have been incorporated into artworks which gave rise to new art forms, i.e. new media art (Michael, 2005). Being the main characteristic of new media art, interactivity was detached and developed into a medium of new art form – interactive art (Lev, 2002). It is a form of installation-based art that involves spectators in some ways. Artworks frequently feature computers and sensors to respond to motion, heat, meteorological changes or other types of inputs to which their makers program them to respond (Paul, 2003). The use of interactivity as a communicative tool between artist and spectator as well as an art form originated in the late 1960s. In 1968, Jasia Reichardt arranged The Landmark Computer Art Exhibition Cybernetic Serendipity at the Institute of Contemporary Art (ICA) in London (Reichardt, 1968), which was the first exhibition ever to attempt to demonstrate all aspects of computer-aided creative activity: art, music, poetry, dance, sculpture, and animation. Since then, interactive art has gradually become an important expressive and communicative means of new art.

2.2.3 Interactivity in Design – Interaction Design

Since electronic products and user experience needs were becoming complicated, requirements of interactivity were felt increasingly in the 1980s (Dan, 2006). It is a discipline which defines the behavior of products and systems with which a user interacts. The practice typically centers around complex technological systems such as software, mobile devices, and other electronic devices. Interactivity has become a design form to create dialogues between humans and artifacts (Helen, Yvonne and Jenny, 2007).

The term interaction design was first proposed by Bill Moggridge and Bill Verplank in the late 1980s. To Verplank, interaction design is an adaptation of what the computer science term “user interface design” is to the industrial design profession. To Moggridge, it was an improvement over soft-face, which he had coined in 1984 to refer to application of industrial design to products containing software (Sebastiano and Gillian, 2006).

2.3 Review of Applications of Interactivity in Art and Design

2.3.1 Applications in installations

➢ Particles

Held in the Science Museum, London, the projection in the Particles created silhouettes of observing visitors in the form of glowing, animated particles which they could manipulate to move around the screen and change in an on-going relationship between this technologically mediated space and the participants (Moeller, 2000). See Figure 2-1.

Figure 2-1. Particle.

➢ Wall Showroom

In Wall Showroom (Figure 2.2), a mobile projection surface formed the central element of the installation. As it moved about, the layout of the room was continuously altered, creating new spaces in which information could be disseminated. Viewers followed this projection surface, accompanied by a guide. The idea of the showroom was to demonstrate unification of space, media and movement. Wherever films and information were projected onto the dynamic surface, they directly reflected the content and style of the exhibition. Sound and lighting effects added to the experience (ART+COM, 2002).

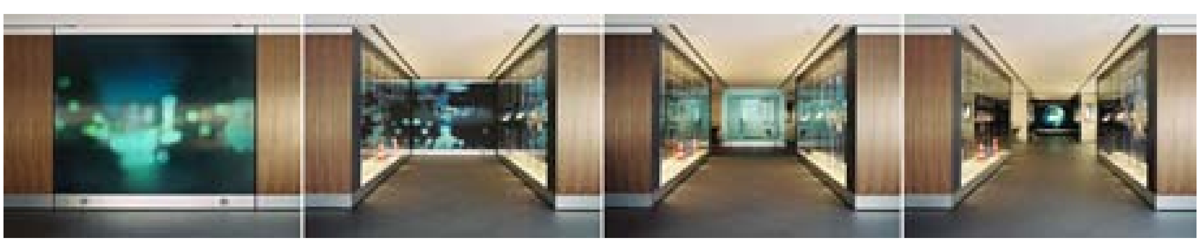


Figure 2-2. Wall Showroom.

- The Famous Grouse Experience

In this "interactive environment" – a room with floor and wall projection – visitors were able to interact with film images in real time. By jumping or stomping they could break the ice projected onto the floor. They could also run across the surface of the water, making waves as they moved (without getting wet). Up to 20 people could enjoy this experience simultaneously (ART+COM for Highland Distillers Ltd., 2002). See figure 2-3.

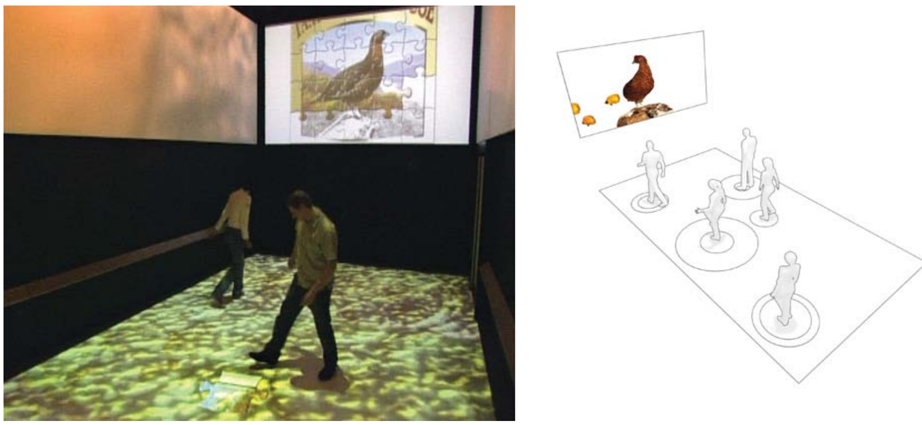


Figure 2-3. The Famous Grouse Experience.

- Liquid Space

Figure 2-4. Liquid Space.

Liquid Space was a space which physically reacted to the behavior of the visitor. Through the use of sensors, software and mechanisms, the space changed in form and sound. If visitors sat silently, Liquid Space would fall asleep, and if there were a lot of activities, the space would become larger and more dynamic. This way, an adaptive situation was created in which visitors and space became one (Roosegaarde, 2003). See Figure 2-4.

- 4D-Pixel

4D-Pixel was a smart surface which physically reacted to voice of visitors and music and showed relievo (sculpted) letters. This interactive sculpture was a merging of electromagnetics, software and electronics. The dynamics of the wall was made of hundreds of pixels which dynamically reacted to sound frequencies. This way a direct relation between human activity and the appearance of the surface was established; it was a kind of fusion between body and machine (Roosegaarde, 2005). See Figure 2-5.

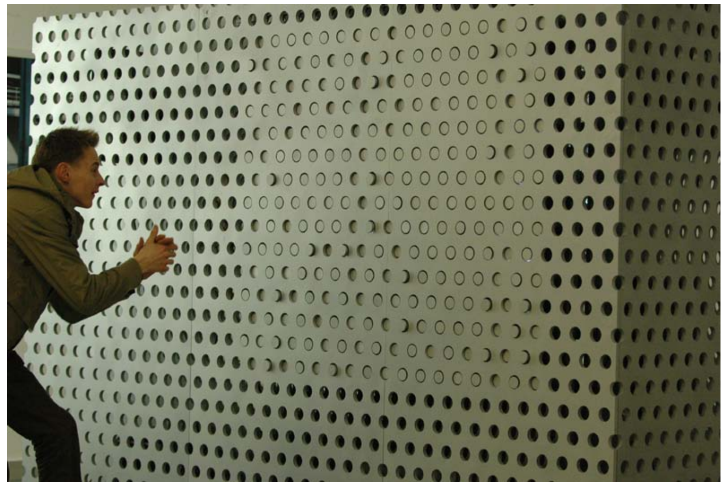


Figure 2-5. 4D-Pixel.

- One installation in the 'Touch Me' Exhibition

Held in Victoria and Albert Museum, London, this immersive installation 'Touch Me' exhibition at the museum was a womb-like ambient space that was based on therapy rooms for the visually impaired, and designed as an immersive 3-D radio that reacted to the touch of visitor and stimulated the sonic, visual and haptic senses through pulsations (Mirti and Testa, 2004). See Figure 2-6.

Figure2-6. 'Touch Me'.

- Floating . numbers

The central element of this installation was a 9-metre long interactive table with a mass of numbers flowing in a continuum on its surface. Individual digits appeared randomly at the surface and once touched by a visitor, surrendered their secret text, pictures, films and animation. The significance of the numbers materialized from the various perspectives of science, religion, art or outlook of visitor on everyday life. A large-scale projection system and a touch-sensitive table surface formed the elements of this media installation. Visitors' exploration of the world of numbers was a fascinating hands-on experience (ART+COM, 2004). See Figure 2-7.

Figure 2-7. Floating . numbers.

- SUTURE

An expanded cinema installation, SUTURE, SCI-Arc encouraged visitors to experiment with media assemblage and play with the possibilities of film. A landscape of sculpted furniture and pressure sensors embedded in the floor organized circulation flows and points of view, allowing visitors to create new signal paths and new cycles between images projected on multiple screens. By acting as catalysts, the users were able to make new connections between gestures, objects, characters, materials, spaces and narrative arcs, ultimately remixing events (Keller and Leitao, 2005).

- Aperture

Aperture was a facade installation with interactive and narrative display modes. Consisting of an iris diaphragm matrix, the surface of façade with variable opening diameters of its apertures was enriched by a dynamic translucence that created new imagery as well as a new channel for communication between inside and outside (Eyl and Green, 2005). See Figure 2-8.

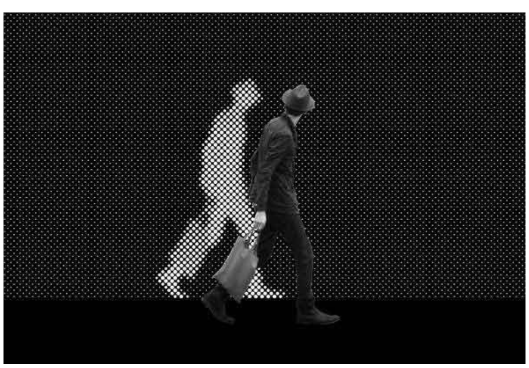


Figure 2-8. Aperture.

- Dotty Tate

In an Octagon, 25 2-metre tall interactive wands with glowing spheres at their top turned only when touched. Bruges made a “live painting” tracking the patterns of audience interaction during the day in London (Jason, 2005). See Figure 2-9.

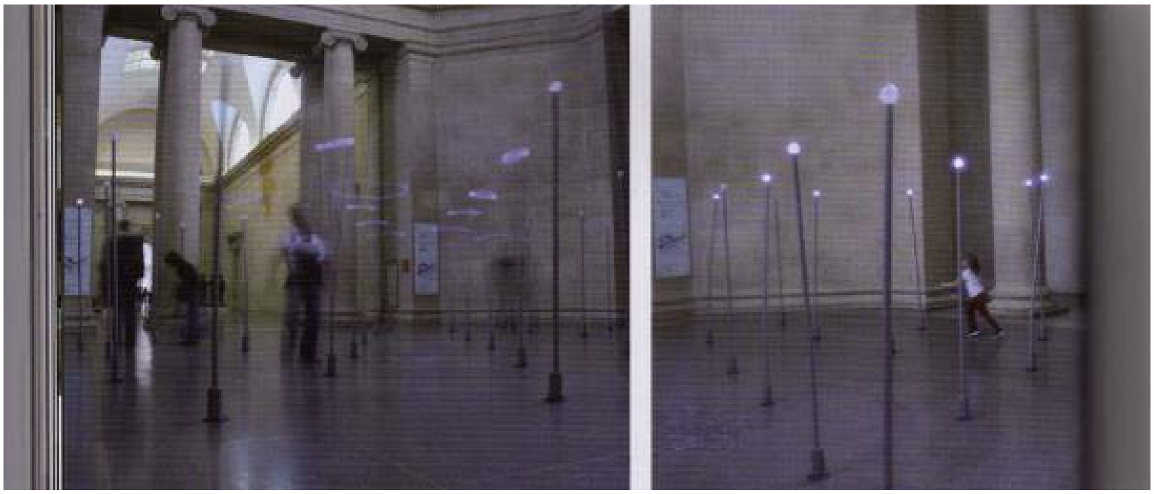


Figure 2-9. Dotty Tate.

- Reactable

The Reactable was a collaborative electronic music instrument with a tabletop tangible multi-touch interface. Multiple performers shared complete control over the instrument by moving and rotating physical objects on the luminous, round table surface. By moving and relating these objects, representing components of a classic modular synthesizer, users could create complex and dynamic sonic topologies, with generators, filters and modulators, in a kind of tangible modular synthesizer or graspable flow-controlled programming language (2005). See Figure 2-10.

Figure 2-10. Reactable.

- Volume

Situated in the Italianate courtyard of the Victoria and Albert Museum, London, for several months, 46 2.5-metre columns formed a grid of LED lights rigged up to an audio system, computer and separate synthesizer networks for each column, which played their own pieces of music. Walking up to it increased the volume but no movement deactivated it. This simple system of rules generated complex emergent patterns as the number of people increased. The arrangement each person heard depended on his or her path through the installation, as well as movements of the people around the individual (UVA, 2006 - 2007).

Figure 2-11. Volume.

- Liquid 2.0

Exhibited in Rotterdam, Netherlands, Liquid 2.0 was an interactive living cocoon which physically adapted to sounds and motion of the visitors (Roosegaarde, 2006a). See Figure 2-12.

Figure 2-12. Liquid 2.0.

- Wind 3.0

Held in Rotterdam, Netherlands, Wind 3.0 existed out of hundreds of fibers which, through a merging of electronics and ventilators, moved and interacted with the visitors (Roosegaarde, 2006b). See Figure 2-13.

Figure 2-13. Wind 3.0.

➢ Plink Plonk

Like an interactive board game, Plink Plonk in the Victoria and Albert Museum had people clustered around a table. On its glowing surface they could play with small sound-input devices disguised as mechanical musical boxes. Moving them around the table provoked a range of decorative, sound reactive light effects (AllofUs, 2006).

➢ Anemograph

Held in the Millennium Galleries, Sheffield. Responding dynamically to changes in the weather, balls suspended in acrylic tubes rose and fell, depending on wind speed and direction. In turn, their changing heights triggered LED lights to glow more brightly (Jason, 2006).

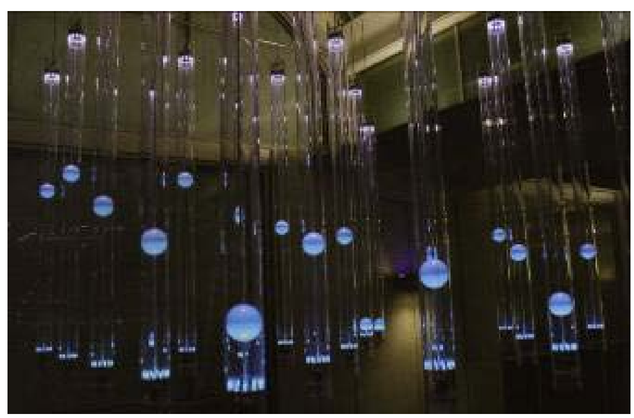


Figure 2-14. Anemograph.

- Dune 4.1_Maastunnel

Held in Rotterdam, Netherlands, Dune 4.1 was an interactive installation that resembled soft reeds, with people around it directly inducing changes in it. A corridor composed of several hundred optic fibers, which reacted to movements of and sounds made by the visitors. This hybrid of nature and technology functioned as a platform on which the relationship between visitors and the existing architecture was enhanced (Roosegaarde, 2007a).

Figure 2-15. Dune 4. 1_Maastunnel.

- Flow 5.0

Figure 2-16. Flow 5.0.

Held in Rotterdam, Netherlands, Flow 5.0 was an interactive landscape made out of hundreds of ventilators which reacted to visitors' sound and motion. By walking and interacting, visitors created an illusive landscape of transparencies and artificial wind (Roosegaarde, 2007b).

- d.v.d

Held in Tokyo Art Exhibition, algorithm-based interactive models of Yamaguchi Takashi put visitors inside a new environment where they could question the effects of their behavior and perceptions of [virtual] data. Centered around a generative-code program, the featured physical-interaction-digital-realization, interactive model pit two drummers against each other in a virtual space where a grounded colorful grid modulated while each drummer played (Takashi, 2007).

Figure 2-17. d.v.d.

- The Football Experience

The life-sized, heavily stylized figure of a football player was placed on a table surface. When visitors touched different parts of the body, they learnt what injuries football players suffered. For example, if a visitor touched a hand, a realistic X-ray image of its bones shined up on it. At the same time, detailed information in textual and graphic form popped up: How often do football players receive this kind of injury and what are usual recovery periods? Additionally, a film showed situations in matches where a player suffered the corresponding injury. Four positions around the figure independently allowed accessing the information so that several football fans could

Figure 2-18. The Football Experience.

playfully enlarge their knowledge at the same time. Choosing Dutch, French, English, or German as the installation language was possible at all times (ART+COM, 2007).

2.3.2 Applications in architectures

- R-G-B

The work of R-G-B showed computer controlled colored lights filling 81 windows extending over 180 meters at the Southern California Institute of Architecture (SCI-Arc.) Patterns were controlled by cellphone by any caller from any location, raising issues concerning private interaction and control of public spaces (ELECTROLAND, 2001). See Figure 2-19.

Figure 2-19. R-G-B.

- Axial Rings

The Axial Rings had twenty-two interactive rings extended to 140 meters along the primary walkway of a university in Krems, Austria, connecting disparate buildings and the surrounding city. The rings were conceived as the symbolic heart of the campus, glowing and changing colors in response to sensors that could detect human proximity, levels of motion and activity, sound, and even nearby cellphone

Figure 2-20. Axial Rings.

usage. When two individual rings were made to light up, all of the intermediate rings between them would light up. Thus visitors could connect to each other via the rings over long distances. The rings also displayed "default" patterns that were specific to the time of day, and exterior light and temperature levels. Like a large digital clock, they marked the hour and half-hour (ELECTROLAND, 2004).

- Interactive Walkways

Figure 2-21. Interactive Walkways.

This project featured two glass pedestrian bridges designed as 'Interactive Walkways', each with LED lights embedded in resilient walking surfaces. Sensors detected the presence of people and the system triggered interactive light patterns on the walkways (ELECTROLAND, 2005a).

- City National Plaza Towers

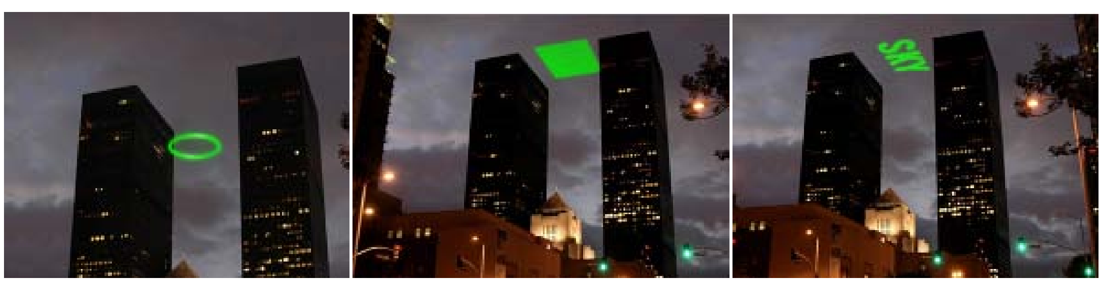


Figure 2-22. City National Plaza Towers.

An interactive ring sat in the plaza, between the twin towers. At night it rose slowly and took its place 150 meters up in the sky. It changed color and intensity in response to activity along a circular paving in the plaza below. The Sky Mesh was suspended between the tops of the twin towers. It featured a grid of LED lights spaced 1.5 meters apart on a steel cable grid (ELECTROLAND, 2005b).

- Connection

The ceiling of a pedestrian bridge 82 meters long was covered with a field of interactive lighted "dots". The dots would light up directly over a walking pedestrian or create visual connections between several pedestrians. The dots also inhabited the space as autonomous playful entities, racing around with each other like squirrels in a tree (ELECTROLAND, 2008).

Figure 2-23. Connection.

- Target Interactive Breezeway

The Target Interactive Breezeway offered a unique Target branded interactive experience adjacent to the newly reopened Rockefeller Center top floor observation deck. The Interactive Breezeway engaged pedestrians in an ephemeral interactive encounter where their positions and paths were traced by colorful avatars and effects (ELECTROLAND, 2006a).

Figure 2-24. Target Interactive Breezeway.

- ENTERACTIVE

ENTERACTIVE was a project in Los Angeles, California. It consisted of a luminous field of LED lights embedded into the entry walkway that responded to the presence of visitors; a

Figure 2-25. ENTERACTIVE.

massive display of lights on the building face that mirrored the patterns of the entry; and video displayed in the lobby and entry areas. Environmental intelligence and surveillance of human activity were combined with a video-game sensibility (ELECTROLAND, 2006b). See Figure 2-25.

- LUMEN

Figure 2-26. LUMEN.

It was a site specific project where the walls of the main stairwell of the Design Triennial Exhibit of the Smithsonian /Cooper Hewitt National Design Museum in New York were lined with a translucent skin that emitted engaging light patterns and sounds as visitors ascended and descended the stairwell. Electroland worked with several technology partners to realize this exhibit. Lightolier provided the fluorescent T-5 fixtures. Sylvania provided technical assistance and the 75 T5 bulbs and Quicktronic dimming ballasts allowed rapid dimming and control (ELECTROLAND, 2006-2007).

- Duality

For a new building complex in downtown Tokyo, ART+COM had developed an artistic installation on the bank of an artificial pond at the exit of the Osaki metro station. The project dealt with the duality between liquid/solid, real/virtual and water ripples/light waves. Pedestrians walked over a 6x6 meters large LED plane, installed right on the edge of the water. The LEDs were covered with translucent glass diffusing their light. With their steps, the passers-by provoked virtual waves on the LED plane in real-time. When these waves hit the edge of the pond, they were extended into the water as real ripples. Contrary to the usual practice of art in public space, the installation aimed at creating an identity for the space, based on the space. Passers-by flowing from the metro station were offered a moment of contemplation (ART+COM, 2007). See Figure 2-27.

Figure 2-27. Duality.

- Living City

Presented at Interactive Architecture & Media symposium, Living City was a platform for the future where buildings talked to one another. It was an exploration of the vitality of the city through new forms of public space, air and façade, i.e. a prototype façade that breathed. The project was based on the belief that in the era of ubiquitous computing, as sensors disappear into the woodwork and all kinds of data are transferred instantly and wirelessly, buildings will communicate information about their local conditions to a network of other buildings. Architecture will come to life. Living City is an ecology of facades where individual buildings collect data, share it with others in their social network, and respond to the collective body of knowledge. Public space in the city will be everywhere. Air will be public space. Building facades will be public spaces. Both will belong equally to everyone in the city, no less valuable than the traditional fixed public spaces of parks and streets. At the intersection of air and facades, public space will be distributed and will be dynamic.

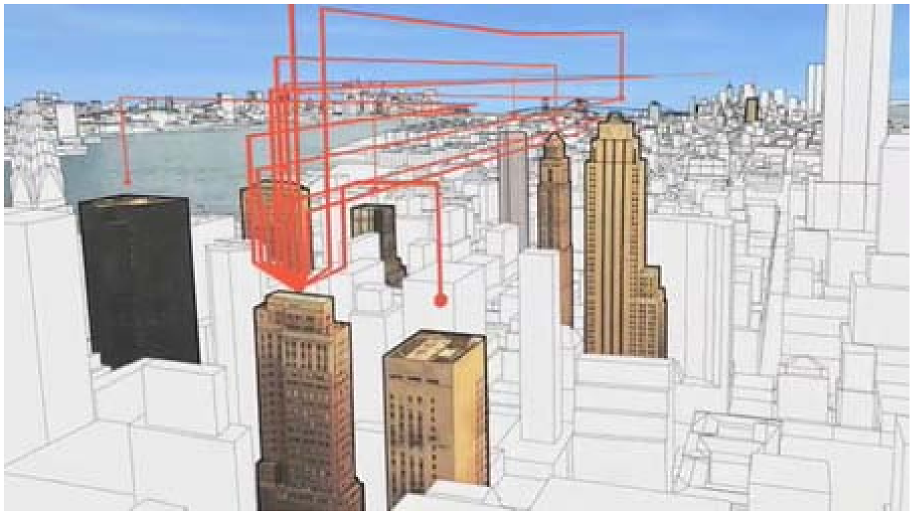


Figure 2-28. The blueprint of Living City.

Architecture will come to life. Living City will define air and building facades as public spaces. Walls will breathe. Construction materials and systems that have been inert for thousands of years will respond in real time to the dynamic conditions of their surroundings and to a larger network of data. Buildings will host public interfaces to air and make visible the invisible conditions of the environment. Architecture will come to life. Living City is a full-scale building skin designed to open and close its gills in response to air quality (The Living, 2008).

2.3.3 Applications in products

- Microsoft Surface

In 2001, Stevie Bathiche of Microsoft Hardware and Andy Wilson of Microsoft Research began brainstorming concepts for an interactive table. Their vision was to mix the physical and virtual worlds to provide a rich, interactive experience. In early 2003, the New Consumer Products Group, led by David Kurlander, presented the idea to Bill Gates, Microsoft Chairman, and within a month the first prototype was born, based on an IKEA table with a hole cut through its top and a sheet of architect velum as a diffuser. The

Figure 2-29. Microsoft Surface product.

evolution of Microsoft Surface had begun. As more applications were built, the team saw the value of the surface computer beyond simple gaming and began to favor those applications that took advantage of the unique ability of Surface to recognize physical objects placed on the table. In 2004, the team grew and became the Surface Computing group. Surface prototypes, functionalities and applications were continuously refined. The team built more than 85 early prototypes for use by software developers, hardware developers and user researchers. Today, Microsoft Surface is a 30-inch diagonal display table that is easy for individuals or small groups to use collaboratively. With a sleek, translucent surface, people engage with Surface using natural hand gestures, touch and physical objects placed on the surface (Microsoft, 2001 – 2007).

- Light: Airswitch

Airswitch was a brilliant and magical interface to control the light by Mathmos in the UK. Place a hand above the Airswitch to turn the light on and control the brightness by the distance between the unit and the hand. Wave hand across the unit to turn it off. It was a frosted flask shape glass body that intelligently lighted up one's room (Mathmos, 2005).

Figure 2-30. Airswitch Light.

➢ Hanabi

The heat of the bulb made this shape-memory alloy lamp 'bloom' whenever the light was turned on. Hanabi, the Japanese word for 'fireworks', literally means 'flower + fire.' Both flowers and fire fade away so quickly and easily. Like its namesake, this light flickered between beauty and disappearance (Neodo, 2006).

Figure 2-31. The motional Hanabi.

➢ Sunshine

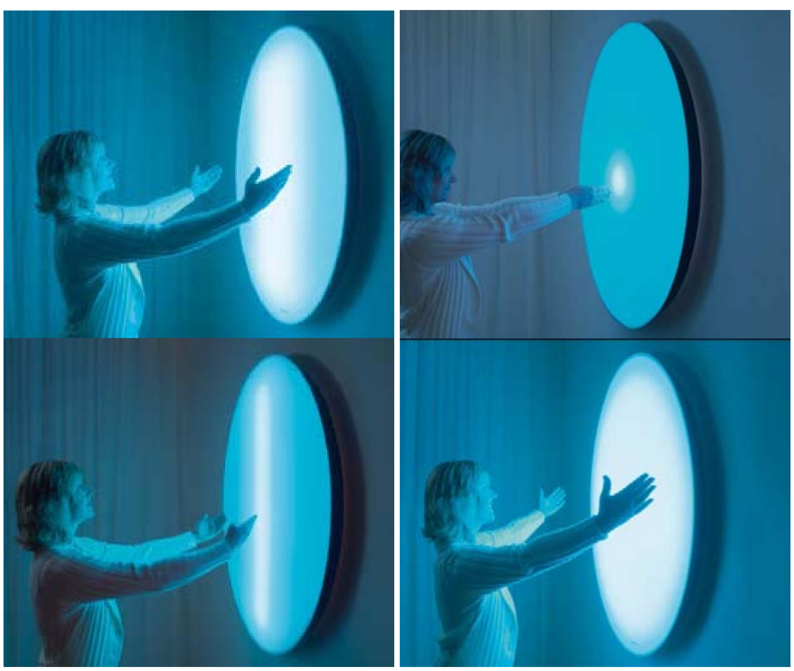


Figure 2-32. The interaction process of 'Sunshine'.

Sunshine was a large, wall-mounted disk whose changing light qualities helped prevent Seasonal Affective Disorder by positively affecting the 'bio-clocks' of people in its vicinity. Sunshine compensated for the lack of light from outside and simultaneously let people make use of its energizing blue light mode when they felt especially tired. Sunshine 'sensed' the level of light outside – as well as the color 'temperature' – and compensated for indoors light when needed. Its outer 'ambilight' ring projected onto the wall a constantly changing glow that imitated natural light rhythms and engendered a pleasant 'outside-in' feeling for people close by. Its overall surface also emitted a bright, yellowish light when it was dark outside to ensure that one had the right amount of light inside during the day. At any time of the day, if one felt tired, one only had to turn the active blue light of Sunshine on. To do this, one stood before it and moved one's arms as if one was opening or closing a set of curtains. The more one 'opened' them, the more light one received; the more one 'closed' them, the less light one received (PHILIPS Research, 2006a).

- Coach

In this application, as soon as one imitated the Coach, In Shape recognized his movements and started counting the repetitions. Coach was able to detect bodily movements and heat generated. Here, the inputs were temperature and touch/movements, registered by sensors as tactile movements. These inputs were processed electrically and electronically, and were actuated as outputs in the forms of optical data and sound (PHILIPS Research, 2006b).

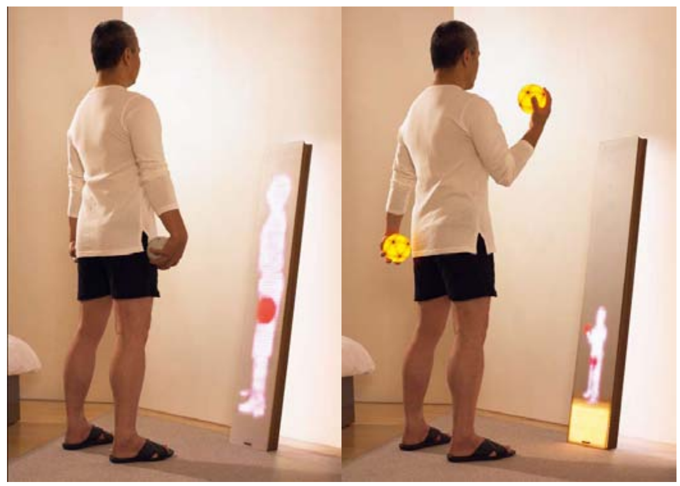


Figure 2-33. Coach.

- Versa Tiles

Versa Tiles was a system of interactive, modular tiles that enabled children and teenagers – even adults – to play a variety of physically demanding games on the floor of any room. The system consisted of a set of identical, pressure-sensitive

Figure 2-34. A part of 'Versa Tiles'.

Play Tiles that acted as a gigantic interactive floor display, a Master Tile that brought power and intelligence to other tiles, and a couple of smart 'pucks' for specific games (PHILIPS Research, 2006c).

- Drag and Draw

Drag & Draw was a set of digital drawing tools that enabled toddlers – and older children – to turn their home into a larger-than-life virtual drawing canvas. Drag & Draw consisted of a multi-color Brush, an Eraser, and a Magic Wand to bring their drawings to life and last but not least, a Bucket to project the virtual drawings onto the wall (PHILIPS Research, 2006d).

Figure 2-35. The changing of 'Drag and Draw'.

- Chameleon

The Chameleon was a lampshade that changed to match any color people 'show' it, as easily, and as often, as they like. When synchronized with Light Spectrum, Chameleon matched the color of the Sunlight shade to harmonize the lighting ambience one had chosen (PHILIPS Research, 2006e).

Figure 2-36. Chameleon.

- Music Spectrum

Music Spectrum was a music system that enabled people to create a musical mood from a whole spectrum of feelings. It consisted of a single loudspeaker offering surround sound from any spot in the room and Music Control, a wireless interface enabling people to explore their mood intuitively through the music itself, rather than reading through menus and play

Figure 2-37. The motional Music Spectrum.

lists (PHILIPS Research, 2006f).

- iBar™

The iBar™ was the first commercially available multi-touch, interactive, customizable bar in the world. It was taking its place in history as a pioneering example of interactive technology. One control over the interactive surface created revenue by offering sponsors and advertisers a chance to communicate with its guests in a captivating and effective way (Mindstorm, 2007a).

Figure 2-38. iBar™ .

- iWall™

The iWall™ could transform any standard wall into a fully responsive and interactive surface. It could be bought or hired as a front- or rear-projected system. It was an amazingly flexible design tool and could create a venue that never got dull or tired. One could transform the venue from underwater world to techno lounge in an instant and fill walls with touch-sensitive interactive information (Mindstorm, 2007b).

➢ Smoking Lamp

Smoking Lamp was an object that amplified the personal choice of smoking or not smoking in a public environment. It was designed as a funnel that terminated with a ring of light, the lamp changed from a bright white to a warm pink if it detected nicotine smoke beneath it. The light emitted corresponded with the new situation, illuminating the particles being exhaled by the smoker, and placing the smoker inside a theatrical scene (HeHe, 2005 – 2007).

Figure 2-39. Smoking Lamp.

2.4 Introduction of Electronic Technology

Electronics is the branch of science and technology which makes use of the controlled motion of electrons through different media and vacuum. In this research, the happening of Interactivity has a close inter-relationship with Electronic Design. Electronic design technology is the base technology for setting up interaction processes and operating the whole system of interactive fashion.

2.4.1 The recent development of electronic technology

Electronic technology related to the study includes the following three areas:

EDA (Electronic Design Automation) technology; microelectronic technology; and embedded system design. All of them at the cutting edge of current development of electronic technology.

◆ Electronic Design Automation (EDA) technology

Electronic Design Automation (EDA or ECAD) is a category of software tools for designing electronic systems such as printed circuit boards and integrated circuits. The tools work together in a design flow which chip designers use to design and analyze entire semiconductor chips. Currently, EDA technology is playing a significant role and has been widely used in product design and manufacturing, teaching and research. In product design and manufacturing, EDA technology can realize preliminary computer simulation, system-level simulation and test environment simulation, circuit board welding and ASIC design, etc (Dirk, 2003). In scientific research and product development, it can be directly applied to chips for small-batch products or the preliminary development of chips for high-volume products. The upgrading and technological transformation of traditional mechanical and electrical products can improve the performance of traditional products, reduce volume, and increase the technological content and added value of products (Franz, 1995). EDA technology is not only used in preliminary computer simulation and product testing, but it also plays an important role in the development and production of electronic devices, circuit board welding, etc.

◆ Microelectronic technology

Microelectronics is a subfield of electronics. Microelectronics, as the name suggests, is related to the study and manufacture, or microfabrication, of electronic components which are very small (usually micrometer-scale or smaller, but not always). Microelectronic technology is the basis of information technology (Jerry, 2005). In the early 21st century, silicon CMOS process technology with ever-shrinking size remains the mainstream of microelectronics. With the continuous improvement of IC design and process level, System on Chip (SoC) will be the focus of development, and the combination of microelectronic technology with other disciplines will create new technologies and new industry growth points (Owen, 2000). MEMS (Micro Electro Mechanical Systems) are very small and light mechanically and electrically integrated products which take micron as measurement unit. MEMS refers to the complete micro-electromechanical systems that integrate micro-sensors, micro actuators, signal processing and control circuits, interface circuits, communication and power supply into a whole (Mohamed, 2006). It mainly consists the three parts of micro-sensor, actuator and corresponding processing circuits. It mainly comprises of micro-sensor, actuator and the corresponding processing circuits. It is derived from silicon microfabrication technology and is the product generated by combining such a wide variety of disciplines as microelectronics, material, mechanics, chemistry, sensor, automatic control, etc (Julian, Gardner, Varadan and Osama, 2000).

As techniques improve, the size of microelectronic components continues to decrease. In smaller sizes, the relative impact of intrinsic circuit properties such as interconnections may become more significant. These are called parasitic effects, and the goal of microelectronics design engineers is to find ways to compensate for or to minimize these effects, while always delivering smaller, faster and cheaper devices.

◆ Embedded System design

An embedded system is a computer system designed to perform one or a few dedicated functions often with real-time computing constraints (Steve, 2003). It is *embedded* as part of a complete device often including hardware and mechanical parts. Embedded systems control many devices in common use today.

Currently, apart from some processors that are of 32-bit, most others are of 8-bit and 16-bit embedded Micro-Controller Units (MCU). Embedded MCU is another form of computer application which differs from the general-purpose computer applications mentioned earlier: embedded computer being a specific computer system hidden in various devices, products and systems in the form of an embedded system with highly specialized software and hardware (Claude, Jean and G., 1997). At present, embedded system technology has become the common direction of development of communications and consumption products and possesses such features as small software code, high automation, quick response, etc.

2.4.2 The Impact of electronic technology on art, design and fashion

The development of electronic technology, including that of computer technology and digital technology, has brought revolutionary impact and excitement to traditional art, design and fashion and has generated many new areas, such as computer art, digital design, smart product design, digital printing of fabrics, intelligent clothing and so on.

By the mid-1960s, many artists had tentatively begun to explore the emerging computing technology for use as a creative tool (Nash and Richard, 1970). Many traditional disciplines integrated digital technologies and, as a result, the line between traditional works of art and new media works created by using computers has been blurred. For instance, an artist may combine traditional painting with algorithm art and other digital techniques. Hence the emergence of new art system created by interdisciplinary combination of traditional art and electronics with electronics, computer and digital technology. For example, the term *electronic art* is almost, but not entirely, synonymous to computer art and digital art (Paul, 2003). The latter two terms, and especially the term computer-generated art, are mostly used for visual artworks generated by computers (Wands, 2006). However, electronic art has a much broader connotation, referring to artworks that include electronic elements such as works in music, dance, architecture and performance (Oliver, 2003). It is an interdisciplinary field and so artists often collaborate with scientists and engineers when creating their works, making art expression forms richer and more diversified and expanding the scope of creativity of artists.

Undoubtedly, the development of electronic technology has also brought in unlimited creativeness to the design field. Traditional graphics, product architecture and new design fields are being created by combining them with electronic technology. The continuous development of electronic technology has made many impossibilities possible and changed people's perspectives through ubiquitous designs (William and Malcolm, 1994). Design aims to improve the quality of people's life and ultimately make human life better, while electronic technology, as a means and tool to achieve the design purpose, takes design as a media with electronic technology application and practice at the same time; the two are complementary (Peng, 2001). The ever-increasing humanization of electronic technology development and gradual sophistication of electronic components, such as the above-mentioned micro-electronics and embedded technologies, provide strong technical support and innovation space for design and development of intelligent products, intelligent spatial designs of buildings, multimedia interactive designs, etc.

Originally, electronic technology and the traditional fashion industry had no direct relationship. The traditional clothing industry has continued to be reliant upon manual work and experience for a long time, from fashion design to mass production. It inevitably involves spending significant energy and effort on tedious craftsmanship, which invisibly but greatly constrains the development of creativity and productivity. However, after electronic technology penetrated into industrial manufacturing and with the development of computer electronic automation technology, the traditional pattern making and production modes have been changed drastically. For example, clothing design has embraced CAD technology and digital printing has become a reality. Weaving, embroidery and other processes too involve significant electronic controls and technologies (Sandra, 2006). These new technologies have improved production efficiency and enriched the diversity of fashion design in one way or another. In addition, electronic technology does not play the role of a mere design tool. Nowadays, while manufacturing technologies tend to adopt electronic technologies, the newly developed technologies are beginning to consider human factors. Electronic technology is also being applied directly to design research and development of wearable electronics.

2.5 Introduction of Wearable Electronics Development

The designing of wearable electronics involves the use of some computerized devices or electronic devices that are designed to fit within the clothing worn by people (William and

Alberto, 2009). The earliest wearable electronics can be traced back to the "wearable computer" that appeared in the 1960s, and the first work could be the invention of the pocket watch, which was constructed in 1961 by mathematician Edward O. Thorp, better known as the inventor of the theory of card-counting for blackjack, and Claude Shannon, who is best known as "the father of information theory" (Quincy, 1998). With the rapid development of science and technology, wearable electronics nowadays have overcome a large number of limitations of existing technologies and have become a hot topic in cross-disciplinary research and applications.

2.5.1 The current situation of wearable electronics

Wearable electronics can be incorporated in smart fabrics, wearable e-textiles, intelligent clothing and smart fashion, and related smart wearable accessories.

- Smart fabrics

Smart fabrics are defined as fabrics that are able to sense stimuli from the environment, and react to them by integration of functionalities in the fabric structure. The stimulus, as well as the response, could be thermal, chemical, mechanical, electrical, magnetic or some other form (Jeanne, 2004). The first electro-conductive smart fabric manufactured as a consumer product was marketed under the trade name Elektex. The technology used layers of carbon-impregnated nylon, arranged in a sandwich construction and outputting x-y-z coordinates to sense the position of a touch on the surface (Elektex, 1998). In general, smart fabrics is composed of special fibers and knitted yarn with transmission function. Examples are knitted fabric sensor (a kind of smart fabric produced by interweaving carbon fibers with elastomeric yarn using a knitting process), and Interactive Textile (a kind of smart fabric which integrates wearable electronics with photonics fiber) (Bickerton, 2003). Nowadays, research on smart fabrics related to wearable electronics starts with their needs for different functions. Considerable research and development efforts go into making of a single smart fabric, such as temperature sensitive fabrics specially used for detection and adjustment of temperature changes, heat monitoring fabrics specially used for monitoring physiological changes, and emergency fabrics specially used for probing surrounding working environment that can protect the wearer to some extent (Annalisa, 2010).

◆ Wearable E-textiles

The blossoming research on electronic textiles (or *e-textiles*) seeks to integrate ubiquitous electronic and computational elements into fabrics. To a certain extent, e-textile is a kind of smart fabric (Bradock and Mahony, 1998). Yet its peculiarity lies in that the fabrics have electronics and interconnections woven into them, with physical flexibility and size that cannot be achieved with existing electronic manufacturing techniques. An e-textile can be worn in everyday situations whereas currently available wearable computers hinder the user's movement. E-textiles can also more easily adapt to changes in computational and sensing requirements of an application, a useful feature for power management and context awareness (Martin, 2003). Development of materials and related electronic components suitable for manufacturing e-textiles now provides even greater room for experimentation of wearability of e-textiles, such as, flexible PCBs, micro-chips, microcontrollers, small size sensors, soft circuits, EL wires and so on (Randell, Anderson, Muller, etc, 2005). A lot of e-textiles laboratories are dedicated to research on more diversified wearable e-textiles through existing electronic technologies.

◆ Intelligent clothing and smart fashion

Right now, as devices get smaller and smaller, we often find ourselves with a different electronic device in each pocket. Each technological advance shrinks these devices and integrates them with one another. It is only logical that as these portable devices that connect us, give us information, and allow us to be mobile get smaller and more powerful, we can eventually find ways to integrate them right into the clothing we wear. Intelligent clothing and smart fashion are part of this exciting technology that involves building computing, connectivity and sensing abilities into materials people are comfortable to wear (Ariyatum, Holland and Harrison, 2004). In general, the above-mentioned smart fabrics and wearable e-textiles technologies will be taken as the basis for further research and development of intelligent clothing and smart fashion, which are essentially two sides of the same coin. Based on the needs of intelligent clothing and smart fashion, smart fabrics and e-textiles of different functions can be individually or comprehensively designed. There are various types of intelligent clothing and smart fashion to meet the varying needs in terms of sensory resources and reaction intensity or forms. In respect of sensory resources, some intelligent clothing and smart fashion are designed to sense the surrounding environment only. Some are designed to sense the bodily activities or physical changes, while some possess both (Gilsoo, 2009). Reaction intensity and forms can be defined according to the intelligence level and specific functions of intelligent clothing and smart fashion, while division of intelligence level can refer to the classification of the extent of intelligence used in smart fabrics, which can be roughly divided into passive smart, active smart and very smart (Zhang and Tao, 2001). The reaction forms include changes in visual sensing, auditory sensing, and form as well as information input and processing (Deflin, Weill and Koncar, 2002). In the next few years, intelligent clothing and smart fashion are likely to incorporate even smarter features. These could include certain intermediates, transporters and interfaces for an enormously broad range of micro-systems. The latest innovations would create significant demand for creative capabilities in the clothing industry (Sabine, 2008). The next section lists specific examples of intelligent clothing and smart fashion that have emerged recently, and further explains their current development status.

2.5.2 Review of the latest applications of intelligent clothing and smart fashion

According to the basic classification in the previous section, review of the latest applications of intelligent clothing and smart fashion is also divided into three categories: passive smart, active smart and very smart.

- Passive smart: intelligent clothing and smart fashion having the ability to sense only the environment or something about the wearer (wearable sensors fall into this category) (Zhang and Tao, 2001).

Case 1: Philips HeartCycle

Philips is looking to make clothing that is wearable and yet has medical functionalities and is fashionable. Monitoring body functions has always been intrusive. The patient has to be stationary and wired up. In an effort to combat heart disease and heart failure, HeartCycle aims to collect real-time data of vitals of a patient, in order to monitor functioning of organs and prevent fatalities. This may have far reaching positive effects for cardiac patients (PHILIPS, 2008).

Figure 2-40. HeartCycle.

Case 2: NuMetrex Heart Rate Monitor Sports Bra

Sports Bra uses unique textiles to sense and respond to the body. This sports bra is designed to give women the option to wear a strapless heart rate monitor. The NuMetrex Heart Rate Monitoring Sports Bra works with the Polar WearLink Transmitter. It will also be connectable to most fitness machines that have the Polar Link technology integrated. The sensors are knitted directly into the fabric of the seamless bra. The use of conductive yarn makes it completely integrated into the textile and gives the highest wearing comfort (NuMetrex, 2006).

Figure 2-41. Heart Rate Monitor Sports Bra.

- Active smart: intelligent clothing and smart fashion having the ability to sense stimuli from the environment, as well as to react to them; having the function of a sensor and an actuator (Zhang and Tao, 2001).

Case 3: WiFi detecting T-shirt

Detecting T-Shirts keep getting more stylish. The last introduction of Thinkgeek's Wi-Fi Detecting T-Shirt is already a great looking T-Shirt. It is a bit geeky to

Figure 2-42. WiFi detecting T-shirt.

wear but life should be fun as well. The Wi-Fi Detecting T-Shirt searches for wireless signals in the 802.11b or 802.11g range and shows their signal strength in a Macbook stylized laptop image on the front of the T-Shirt (Thinkgeek, 2004).

Case 4: Signal indicator cycling jacket

This jacket is not like reflective items that exist now. This is an advance in cycling visibility and safety. LEDs on the wrist mounted controls light up when activated to indicate the intentions of direction of the cyclist (Leah, 2007).

Figure 2-43. Signal indicator cycling jacket.

Figure 2-44. EroGear wearable display jacket.

Case 5: EroGear wearable display jacket

EroGear is offering their wearable display integrated in any jacket of your choice. Here are some of the impressive features in their tailor made display jackets: a software package that takes still images and exports them into a proprietary format for use with EroGear displays. Video content is uploaded by first exporting a video file then running it through the software (EroGear, 2007).

Case 6: Pacer suit makes music with movement

This suit transforms every move of your body into sound by transforming your

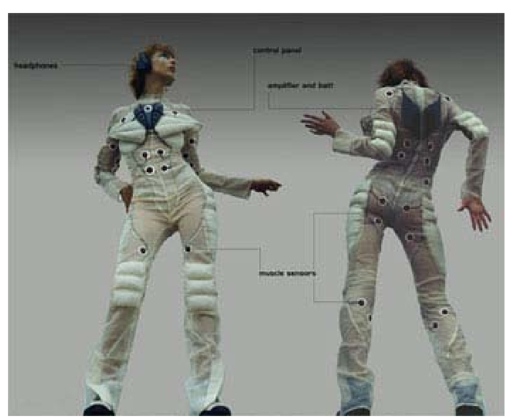


Figure 2-45. Pacer suit.

body into a musical instrument. Muscle movements are detected by the strategically placed sensors integrated into the suit. Muscle movements are then amplified and converted into sound. A control panel on the front allows volume adjustment as well as selection of the type of sound, the rhythm to follow and more (Nikola, 2008).

Case 7: Intelligent clothing for fireman

VIKING strives to reduce the risks of heat stress and burn injuries by providing turnout gear with the lowest possible weight in relation to protection. Integrating thermal sensor technology directly into fabric layers gives the added advantage of indicating critical heat levels before it is too late. Thermal sensors integrated into the inner and outer layers of the coat monitor outer temperature near the fire-fighter and inside of the coat close to the body. Sensors are attached to two LED displays on the sleeve and on the back of the left shoulder (VIKING, 2008).

Figure 2-46. Intelligent clothing for fireman.

- Very smart: intelligent clothing and smart fashion having the gift to adapt their behavior to the circumstances (Zhang and Tao, 2001).

Case 8: iPod control shirt

An Austrian company has released the grooveRider, a t-shirt with iPod controls built into it using 'smart fabric.' The front of the shirt has all the buttons needed to control an iPod (video, mini and nano are supported). The iPod fits snugly in a pocket. The cable routed in the t-shirt ensures that the earphones are well out of the way and do not get entangled while grooving with this shirt (URBAN TOOL, 2006).


Figure 2-47. iPod control shirt.

Case 9. M12™ Cordless Heated Jacket


Figure 2-48. M12™ Cordless Heated Jacket.

The M12™ Cordless Heated Jacket is the answer to cold weather that so many folks and professionals have been waiting for. The M12 is a multi-layered soft shell jacket providing water and wind resistance. Integrated are three carbon fiber heating zones, two on the front and one at the back providing extra heat when needed; three selectable heat settings are available (Milwaukee Electric Tool, 2010).

Case 10. io-Jacket (MP3, mobile-phone and GPS in the Jacket)


Figure 2-49. io-Jacket.

It is based on Interactive-Wear's 'Know-where concept Jacket' with integrated MP3 player and a Bluetooth mobile phone interface. That is basically the 'standard' configuration for a decent Wearable Electronic Jacket. The additional bonus in the io-Jacket is the use of the GPSoverIP function. It can upload data in real time and anyone knowing the website can follow the movement of the wearer in real time (Lodenfrey, 2007).

2.5.3 Interactivity in intelligent clothing and smart fashion design

Interactivity can also serve as an important element to evaluate the intelligence level of intelligent clothing and smart fashion. The level of interactivity, i.e., from passive to active, to interactive and ultimately to communication, is proportional to their intelligence levels.

In the last few years, many textile scientists and electronic engineers have been conducting research on various technologies for textiles and clothing related to interactivity. Besides research on functionality, a few fashion designers have also started to design interactive intelligent clothing and smart fashion. The following examples are the recent applications of interactivity in intelligent clothing and smart fashion design.

- Transfor-Me: Kinetic Dress

Kinetic Dress was a part of the Transfor-Me collection developed for the NEMO Science museum in Amsterdam. The Kinetic Dress changes color and pattern depending on the activity of the wearer (Cute Circuit, 2004a).

Figure 2-50. Kinetic Dress.

- Intimate Memory Shirt

When displaying this design, the designer whispered to her clothes, a microphone on the collar of the shirt picked up the whispers and emitted soft blows which were then interpreted as light. The more intense the whisper, the brighter the lights, which then slowly, like the feeling on the skin, started fading one by one (XS Labs, 2004) .

Figure 2-51. Designer tested Intimate Memory Shirt.

- Transfer-Me: Mystique

This dress changes shape and length during the course of an evening. While in the beginning the dress is pale gray, knee length and has a soft padded surface, at the end of the night it becomes long and smooth, revealing a new color (Cute Circuit, 2004b).

Figure 2-52. 'Mystique' dress.

- Accessory Nerve

This is a Bluetooth mono-sleeve accessory for mobile phones that change pattern (creating pleats on the fabric) when a user receives phone calls (Cute Circuit, 2006a)

Figure 2-53. People wearing 'Accessory Nerve'.

- Hug Shirt

A shirt armed with electronic sensors that gauge body temperature, pressure and heart rate; the Hug Shirt allows wearers to give long-distance embraces to loved ones (Cute Circuit, 2006b).

Figure 2-54. Hug Shirt.

Figure 2-55. SKIN: Dresses.

- SKIN: Dresses

PHILIPS has formulated two conceptual models to detach emotional changes of the wearer through the sensors in the cloth and to project them in visual forms on the cloth. The LEDs developed by Frisson light up and dim according to the degree of excitement of the wearer. This technology is more of an 'analog' phenomenon; like emotion sensing and exploring technologies that are 'sensitive' rather than 'intelligent' (PHILIPS Design Probe program, 2006).

- Photonic Clothing (PHILIPS Research, 2007)

PHILIPS' Lumalive photonic fabric made its debut in clothing and furniture upholstery in 2007. The technology relied on an LED array fabricated on a thin, flexible substrate.

Figure 2-56. Photonic Clothing.

- Smoke Jacket

The jacket has a built-in pair of lungs on the front. As the wearer smokes, the lungs are filled up with exhaled cigarette smoke and begin to gradually darken over time. This project was a result of exploring reflective design as it related to the body, behavioral choices, and information displays (Carswell, 2007).

Figure 2-57. Smoking Jacket.

- Hussein Chalayan Spring/Summer 2007 fashion collection in Paris

Hussein Chalayan presented an unforgettable show. His designs were hailed as innovative by a large part of the international press. His move to bring hi-tech clothing to the catwalk was appreciated widely. Although the interactive fashion that Chalayan presented have remained in incubation stage, a clear message was delivered effectively to inspire designers to place interactive fashion under the spot lights. As seen in Figure 2.57, the dress initiated changes by itself, according to the plan of the designer (Chalayan, 2007).

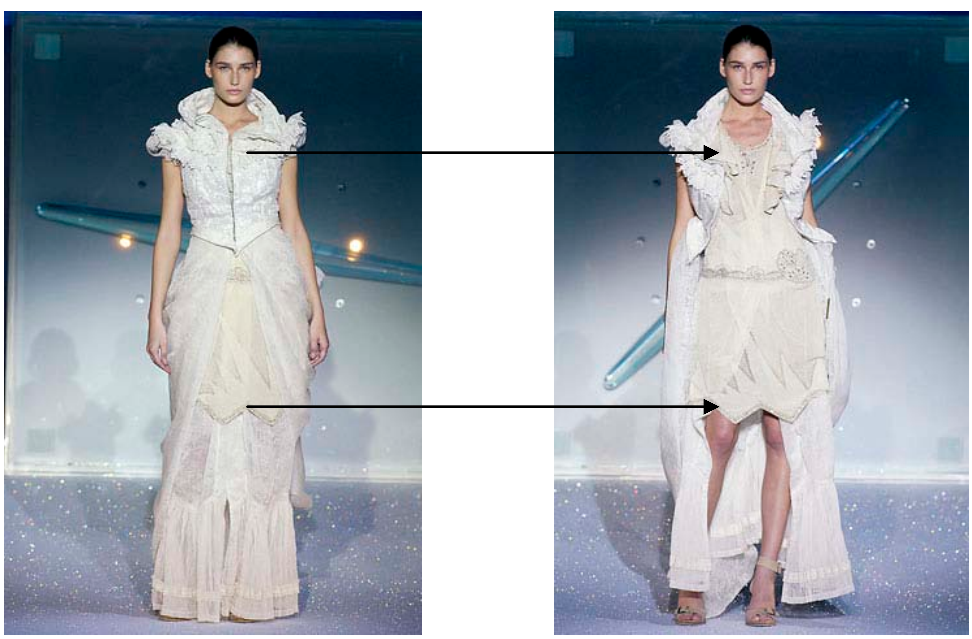


Figure 2-58. One interactive fashion in Hussein Chalayan 2007 Spring/Summer Collection.

- Smart Urban Wear

Austrian designer Wolfgang Langederand the Fraunhofer IZM and Stretchable Circuits (Berlin) have joined forces to develop Smart Urban Wear with focus on innovative displays on clothing. The utope project approaches a textile utopia. The exterior of clothing becomes a display. This creates the possibility to change its surface like a chameleon skin or to use it like a computer display. The integrated display interacts with a smart phone tucked away in a pocket inside the jacket and indicates an incoming call or SMS on the jacket outside (Wolfgang and the Fraunhofer IZM / Stretchable Circuits, 2010).

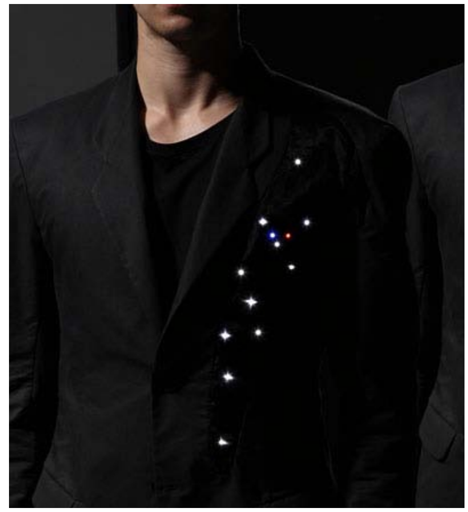


Figure 2-59. Smart Urban Wear.

- 'Intimacy Black' Dress

The new generation fashion-tech designer, Anouk Wipprecht, has used e-foil which transforms from black to transparent. Anouk's design enables the wearer to engage in a wholly 'super-natural' experience with her own skin. The Intimacy dresses are made using wireless, interactive technologies and smart foils that become transparent when electrified. The distance between an onlooker and the garment determines the level of transparency of the garment (Anouk, 2010).

Figure 2-60. 'Intimacy Black' Dress.

- Emotional T-shirt

The Emoticon T-Shirt offers four different emoticons one can choose to express the current stage of one's emotion by lighting up the T-Shirt, making sure that even in the darkest moments of life the emotional stage is clearly visible. One's emotion can range from a happy to sad face, a winking face or a surprised face, covering most of the emotions one goes through while walking through life (2009).

Figure 2-61. Emotional T-shirt.

- Flare dress

A unique and playful concept, the Flare Dress lights up flower-like LED patterns when the wind hugs the body gently, or when there is no wind, one can blow on the flower shapes to make them glow (Stijn, 2009).

Figure 2-62. Flare dress.

Figure 2-63. 'Vanilla Series' of iPhone jackets.

- 'Vanilla Series' of iPhone jackets

Artistic designer Alexander Reeder in collaboration with Yutaka Takahashi and Junpei Wada has linked up the iPhone with a jacket that can contain various modules such as an 8×8 LED matrix display on the back. The iPhone loaded with an application can then turn the back of the jacket into a very personal message board where one can scroll Twitter feeds, show mood status or visualize the beat of a song (Alexander, Yutaka and Junpei, 2010).

- Climate Dress – CO2 sensing fashion

The Climate Dress is made of conductive embroidery and contains over a hundred LEDs inserted into the embroidery. The twist on this dress: it includes a CO2 sensor which monitors the surrounding air for CO2 level, sends the data to a LilyPad Arduino, which then visually indicates the pollution level by LED light patterns on the dress (Danish cooperation, 2009).

Figure 2-64. Climate Dress.

2.6 Introduction of Emotion Psychology on Human Interaction in Social life

Emotion psychology examines emotions from a scientific perspective by treating them as mental processes and behavior and they explore the underlying physiological and neurological processes. In sociology, emotions are examined for the role they play in human society, social patterns and interactions, and culture (John and Elaine, 1992). Interaction is a kind of action which occurs when two or more objects have an effect upon one another. The idea of a two-way effect is essential in the concept of interaction, in contrast with a one-way causal effect (Erving and Joel, 2005).

In social life, human interaction is a dynamic, changing sequence of social actions between individuals (or groups) who modify their actions and reactions due to actions of their interaction partner(s). In modern society, apart from some of the standard and common interactions, with the rapid development of technology, people have begun to search for new ways of interactions, e.g., human-computer interaction, to make up for defects and inadequacies of human interaction and communication (Alan, Janet and Gregory, 2004). So far, research on emotion has remained confined to the field of psychology and cognitive sciences. Yet, emotion plays a very important role in processes of human perception, reasoning and decision-making. Emotion cannot only improve the communication quality among people, but also directly affect the ability of a person to communicate intelligently. Thus, emotion recognition and expression serves very much as message carriers in human interactions and communications. There has been increased emphasis on research on emotion over the past few decades. Emotion has become a branch of psychology in its own right. It has its own niche in sociology, consumers and retailing, computing and design, etc. Much effort has been devoted to shift emotion research from theory to practice (Christian, 2008). In the research area of human-computer interaction in particular, the computer too recognizes emotion to meet people's spiritual needs. The idea of equipping computers with emotional capabilities was first proposed in the U.S. by Professor Marvin Minsky of MIT. In his book The Society of Mind, Minsky pointed out that *"the problem is not whether intelligent machines have emotions, but rather without emotional intelligence can they achieve intelligence."* (1988). Since then, studies on developing computers' ability to identify and express emotions have triggered several waves of research in computer and cognitive science fields. In 1995, Professor Rosalind W. Picard of MIT Media Laboratory first put forward the term 'Affective Computing', and gave it a definition, i.e., affective computing is computing about emotion reaction and emotion affecting aspects. This drew attention from a large number of researchers. The purpose of affective computing is to give computers an emotional intelligence capability similar to that of humans for understanding, using and expressing various emotions. This capability ultimately enables computers to naturally and vividly interact with humans, like humans do (Rosalind, 2000). Nowadays, with high-tech electronic technologies, the aforementioned human-computer interactions may be realized soon. Human-computer interaction can provide convenient life and temporarily ease and comfort loneliness and emptiness inside people's hearts, and yet this is not the ultimate goal of human-computer interaction. Humans' psychological needs will eventually return to the simplest level, while these machines with emotional intelligence can be the media for transformation and realization. All human-computer interactions are ultimately to help people really achieve interactive communication among them (Alan, Janet and Gregory, 2004).

2.7 Summary

Through extensive literature review, the basic definition of 'Interactivity' is understood; an overview of interactive art, a result of application of interactivity in art, as well as interactive design is presented. Review of a large mass of extant literature and visits to recent 'Interactivity' exhibitions enabled collection of a large number of applications cases related to Interactivity in art and design. These include interactivity in installation, in architecture, and in product and other applications. Electronic technologies related to IF were reviewed, including current developments of relevant electronic technologies and the profound impact of electronic technology on art, design and clothing. The current development status of wearable electronics facilitated by combining clothing and textile design with electronic science and technology is described, and the latest applications of intelligent clothing and smart fashion are reviewed. The focus was to understand the current performance of interactivity in intelligent clothing and smart fashion design. Furthermore, the current status of interactive communication as understood by common people in today's society is described from the psychological view point, providing the research background of humanity values and social values of IF for the following in-depth research.

CHAPTER 3

THEORETICAL RESEARCH

3.1 Introduction

This chapter describes the outcome of detailed, comprehensive and in-depth analysis of the concept of interactivity against the theoretical framework, including demystification of the basic process of interactivity, establishment of the relationships and levels of interactivity, and application of them in analyzing specific cases. Further research identifies different key elements and requirements of interactivity with which the basic process of interactivity is further expanded and elaborated.

An independent and systematic theoretical framework of Interactive Fashion (IF) is established, including the definition of IF. Major differences between IF and traditional fashion, design principles of IF, discussion and analysis of the major elements and conditions of IF, and description of the basic interaction processes are provided. Relationships and levels of IF, as transformed from the theoretical framework, and further classification and analysis are presented in detail. This theoretical foundation serves as the basic guideline to further explore practical design research and design creations of IF.

Based on the macro-overall and in-depth understanding of the theoretical framework of interactivity and the theoretical system of IF, further in-depth analysis of the theoretical basis of IF emotion recognition, including definition of emotion (i.e., theoretical concepts of human emotions involved in this study from the viewpoint of emotion psychology) and models of emotional recognition classification (i.e., theoretical foundation for emotion models suitable for IF design) is conducted. Besides, detailed exploration and deconstruction of application of emotion's physiological signals in emotion recognition were conducted to establish in practical research induction detection electronic systems suitable for emotional physiological signals in IF design.

3.2 Theoretical Framework of Interactivity

3.2.1 The basic process of Interactivity – interaction process

The basic process of interactivity is summarized below:

<u>Input → Sensors → Processor → Actuators → Output</u>

This process is based on sensory reception and reaction. In other words, when external sensory information is detected by sensors, it is processed and actuated as output. Such output is detected by other sensors as input, and the process of loop interaction continues (Buurman, 2005). The representational forms during a basic interactive process are summarized in Table 3-1 below.

Input	Sensor	Processor	Actuator	Output
Optical data Scent Sound Temperature/Humidity Touch/Movement Etc.	Audio Olfactory Tactile Visual Others	Mechanic Electric Electronic Etc.	Audio Olfactory Tactile Visual Others	Movement Vision Scent Sound Temperature/Humidity Etc.

Table 3-1. Various representational forms during a basic process of interactivity.

Very often, external inputs take different forms. Such inputs are received by appropriate sensors and are processed. Appropriate actuators respond to inputs in various forms (Buurman, 2005). For example, sound and motion from a subject is sensed, detached, processed and responded to in a combined form of visuals and rhythms.

3.2.2 The relations and levels of interaction processes

Relations and levels of interactivity are summarized in Table 3-2 below:

Relation		Level
Artifact→ Environment [a]		Non-interactive [N]
Artifact → Human [b]		
Environment → Artifact → Environment/Human [c]		Reactive [R]
Human → Artifact → Environment/Human [d]		
Human ⇄ Artifact [e]	Subject ⇄ Artifact [f]	Interactive [I]
Human A ⇄ Artifact A ⇄ Artifact B ⇄ Human B [g]		Communicative [C]

Table 3-2. The relations and levels of interactivity.

- **Sorted by Relations of interactivity:**

Relation 1: a. Artifact → Environment

b. Artifact → Human

In Ration 1, the artifact influences environment or human directly through a prescribed course.

Relation 2: c. Environment →Artifact → Environment/Human

d. Human →Artifact → Environment/ Human

In Ration 2, artifact can take in information from environment or human and responds to them. This process is not yet recurring.

Relation 3: e. Human ⇄ Artifact

f. Artifact ⇄ Artifact

In Relation 3, the interactivity is a recurring process.

Relation 4: g. Human A $\rightleftarrows$ Artifact A $\rightleftarrows$ Artifact B $\rightleftarrows$ Human A

In Relation 4, the occurrence of interactivity is transformed from direct contact to a more sophisticated interactive course. It can take place through wireless communication, and is recurring.

- **Sorted by Levels of interactivity:**

Level 1: Non-interactive	Relation 1:	a. Artifact → Environment
↓		b. Artifact → Human
Level 2: Reactive	Relation 2:	c. Environment→ Artifact → Environment/Human
↓		d. Human→ Artifact → Environment/ Human
Level 3: Interactive	Relation 3:	e. Human $\rightleftarrows$ Artifact
↓		f. Artifact $\rightleftarrows$ Artifact
Level 4: Communicative	Relation 4:	g. Human A $\rightleftarrows$ Artifact A $\rightleftarrows$ Artifact B $\rightleftarrows$ Human B

Classification of level of interactivity is primarily based on interactive relationships between artifact, environment and/or humans as well as the artifact's ability to interact. It ranges from passive direct transmission of message (non-interactive) to reception of message and response (reactive) to active reception of message and response (interactive) and passive voluntary interflow (communicative).

Validation of the theoretical system through several cases is done below.

3.2.3 Study of typical cases

Case 1. Anemograph

In this work, responding dynamically to changes in the weather, balls suspended in acrylic tubes rise and fall, depending on wind speed and direction. In turn, their changing height triggers LED lights to glow more brightly (Jason, 2006). The basic process and forms of interactivity of Anemograph is shown in Table 3-3.

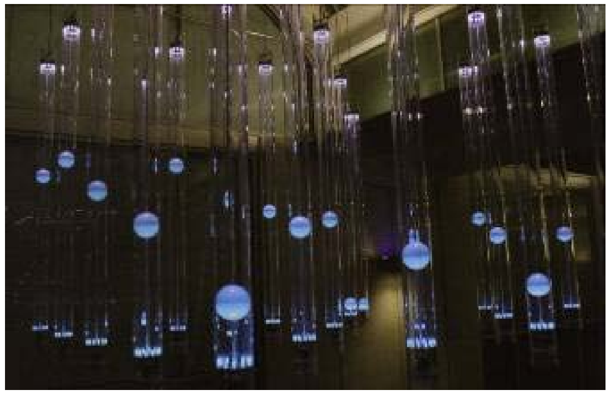


Figure 3-1. Anemograph.

Input	Sensor	Processor	Actuator	Output	Relation	Level
Temperature / Humidity	Tactile	Mechanic Electric Electronic	Visual Tactile	Optical data Movement	Environment → Artifact → Environment/human [c]	Reactive [R]

Table 3-3. The basic process and forms of interactivity of Anemograph.

Case 2. Dune 4.1_Maastunnel

Dune 4.1 is an interactive installation that resembles soft reeds, with people around it directly inducing changes in it. In a corridor, several hundred optic fibers react to movement and sound made by the visitors. This installation is a platform on which the relationship between visitors and the existing architecture gets enhanced (Roosegaarde, 2007). In this case, the inputs are sound, touch and/or movement, registered by sensors such as audio and tactile movement in real time. These inputs are processed electrically and electronically, and are actuated as outputs in the forms of optical data and sound. The level of interactivity in this case is of reactive level, presented in Table 3-4 below.

Figure 3-2. Dune 4.1_Maastunnel.

Input	Sensor	Processor	Actuator	Output	Relation	Level
Sound Touch/Movement	Audio Tactile	Electric Electronic	Audio Visual	Optical data Sound	Human ⇄ Artifact [e]	Interactive [I]

Table 3-4. The basic process and forms of interactivity of Dune 4.1.

Case 3. iBar™

The iBar™ is the first commercially available multi-touch, interactive, customizable flat surface that can be used in liquor bars and pubs as the table top. This is taking its place in history as a pioneering example of interactive technology (Mindstorm, 2007). The interactive surface creates revenue by offering sponsors and advertisers a way of communicating with their guests in a captivating and effective way.

Figure 3-3. iBar™ .

Input	Sensor	Processor	Actuator	Output	Relation	Level
Touch/ Movement	Tactile	Electric Electronic	Visual	Vision	Human ⇄ Artifact [e]	Interactive [I]

Table 3-5. The basic process and forms of interactivity of iBar™.

Case 4. Smoking Jacket

Smoking Jacket has a built-in pair of lungs on the front. As the wearer smokes, the lungs fill up with the exhaled cigarette smoke and begin to gradually darken over time (Carswell, 2007). In this example, the input is smell, being registered by olfactory sensor. The input is processed

Figure 3-4. Smoking Jacket.

electronically, and is actuated visually as outputs in the form of optical data.

Input	Sensor	Processor	Actuator	Output	Relation	Level
Scent	Olfactory	Mechanic	Visual	Vision	Human⋛ Artifact [e]	Interactive [I]

Table 3-6. The basic process and forms of interactivity of Smoking Jacket.

The four examples cited here primarily use audio, visual and tactile sensors for interactivity. For example, the input of an audio sensor is sound; input of a tactile sensor is touch/movement and temperature/humidity; and input of a visual sensor is optical data. Sensitivity of a sensor affects the speed and quality of its interactivity. In general, inputs are processed electrically and/or electronically and are output as optical data and/or sounds whereas those processed mechanically are output as movement.

From the organization and analysis of inputs and outputs of the cases, a generalized theoretical system of intra- and inter-relationships of interactivity is established. The system further categorizes interactivity into three levels, namely, reactive, interactive and communicative. Among them, communicative is the most sophisticated of the three levels of interactivity due to its multi-interactive subject-human relationships and relatively complicated course of interactions. This level of interactivity also requires sensors with a higher level of sensitivity.

3.2.4 Identification of the key elements and requirements

In Practical System of Interactivity, the first key point is to explore and identify requirements for respective elements applied in the interaction process.

Input	Sensor	Processor	Actuator	Output
Optical data Scent Sound Temperature/Humidity Touch/Movement Etc.	Audio Olfactory Tactile Visual Others	Mechanic Electric Electronic Etc.	Audio Olfactory Tactile Visual Others	Movement Vision Scent Sound Temperature/Humidity Etc.

Table 3-7.Various representational forms during a basic process of interactivity.

According to various representational forms during the basic process of interactivity, from the theoretical system of interactivity, there are five elements which are referred to as 'inputs'. They are optical data to vision; scent to olfaction; sound to hearing; temperature and/or humidity to feeling; and touch and/or movement to tactility. Each element or 'input' relates to a corresponding sensor. Visual sensors incept optical data, olfactory sensors sense scent, audio sensors incept sound; and tactile sensors feel temperature or humidity, and also touch or movement (Cooper, Reimann and Cronin, 2007). Table 3-8 below summarizes different input elements, their corresponding sensors, and the specific devices and materials that are required to perform interactivity.

Input Elements	Corresponding Sensors	Specific Devices & Materials
Optical Data	Visual sensors	Mini Camera
Scent	Olfactory sensors	Smoke detector
Sound	Audio sensors	Audio frequency sensor Mini microphone Sound-peak detector
Temperature	Tactile sensors	Heat sensor Temperature detector
Humidity	Tactile sensors	Humidity detector
Touch / Movement	Tactile sensors	Pressure sensor Motion sensor Touch sensor

Table 3-8. Input elements with corresponding sensors and specific devices/materials.

Processor as an intermediate link in interactivity not only performs the data transmission function but also acts as a data converter. It converts the information received by sensor(s) into data and further converts such data into another set of data expressed as specific outputs through an actuator interface. Thus, depending on specific requirements, processors are generally mechanical, electrical or electronic devices (Buurman, 2005). Table 3-9 below summarizes the specific devices of processor requirements.

Processor Requirements	Specific Software
	Wires Transfer Channel
	Wireless Transfer Channel: Wi-Fi, Bluetooth, mobile devices, etc.

Table 3-9. The specific devices of processor requirements.

Inputs are received by the corresponding sensors whereas outputs are presented by the corresponding actuator interface(s). Table 3-10 lists specific devices and materials used in presenting their respective outputs.

Output Elements	Corresponding Actuators	Specific Devices & Materials
Optical Data	Visual actuators	LEDs or OLEDs display
Scent	Olfactory actuators	Scent volatilization device
Sound	Audio actuators	Micro loudspeaker Media player
Temperature	Tactile actuators	Micro-chip warming devices Micro-chip cooling devices
Movement	Tactile actuators	Shape memory materials Simple motional devices

Table 3-10. Output elements with corresponding sensors and specific devices/materials.

3.2.5 Further classification of interaction process

The enhanced basic interaction process is:

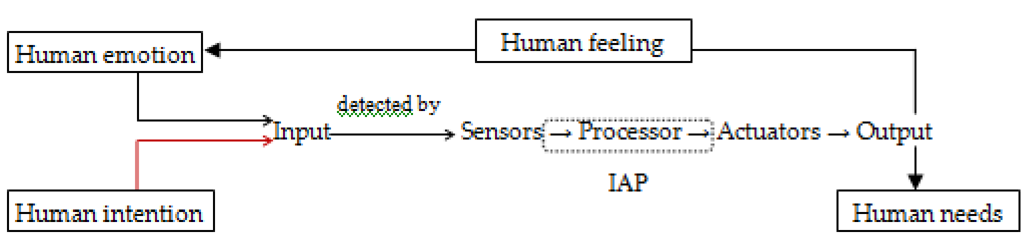


Figure 3-5. The enhanced basic interaction process.

Based on the basic process and the relations and levels of interactivity, the enhanced basic interaction process focuses on the interaction relation between humans and interactive artifacts. Human emotions and intentions are the primary inputs. Research in psychology proposes that human emotions include happiness, sadness, anger, excitation and equilibrium. Human emotions trigger emotional reactions. Here, emotional reaction refers to physio-biological reactions of the body such as breathing rate, heartbeat, pulse, skin temperature and sudation, etc., under psychological influences. Prior research in psychology has made available quantitative data of various human emotional responses as standard references. For example, breathing rate is 17 times per minute when a person is happy and only 9 when he/she is not. It reaches 20 times per minute when a person is in fear, and can be as high as 40 times per minute when angry (Paul and Anne, 1981). Different emotional reactions trigger different forms of inputs and are detected by the corresponding sensors. The output generated, in turn, influences human feelings, and ultimately has effects on the emotional being of a person. Another source of influence is human intention. Human intentions constitute self-initiated inputs to an interactive artifact based on individual desires of a person. Examples are sound command. Generation of output of this type is designed to meet specific human needs. Table 3-11 is a summary.

<table>
<tr><th>Human emotion</th><th>Emotional Reaction</th><th>Input</th><th>Sensor</th><th>Processor</th><th>Actuator</th><th>Output</th><th rowspan="2">Human Feeling</th></tr>
<tr><td>Happiness
Sadness
Anger
Excitation
Equilibrium</td><td>Breath
Heartbeat
Pulse
Skin-temperature
Sudation</td><td rowspan="2">Optical data
Scent
Sound
Temperature
Humidity
Touch/ Movement
Etc.</td><td rowspan="2">Audio
Olfactory
Tactile
Visual
Others</td><td rowspan="2">Mechanic
Electric
Electronic
Etc.</td><td rowspan="2">Audio
Olfactory
Tactile
Visual
Others</td><td rowspan="2">Movement
Vision
Scent
Sound
Temperature
Humidity
Etc.</td></tr>
<tr><td>Human intention</td><td></td><td>Human needs</td></tr>
</table>

Table 3-11. Various representational forms during the enhanced basic interaction process.

The principal part which consists of sensor, processor and actuator is called the Interactive Artifact (IA). The interface of a sensor, actuator and processor collectively constitute what is called Interactive Artifact Program (IAP The main interactive manipulation occurs when the data are transferred from sensors to actuators. Thus interface through which sensor data are transferred to actuator through a processor is broadly summarized as Interactive Artifact Program. It is the core of the whole Interactive Artifact.

To further clarify the aforesaid summary, Figure 3-6 below selects three of the most common inputs, i.e., sound, temperature, touch and/or movement as the sources of influence to present the basic process of interactivity in detail.

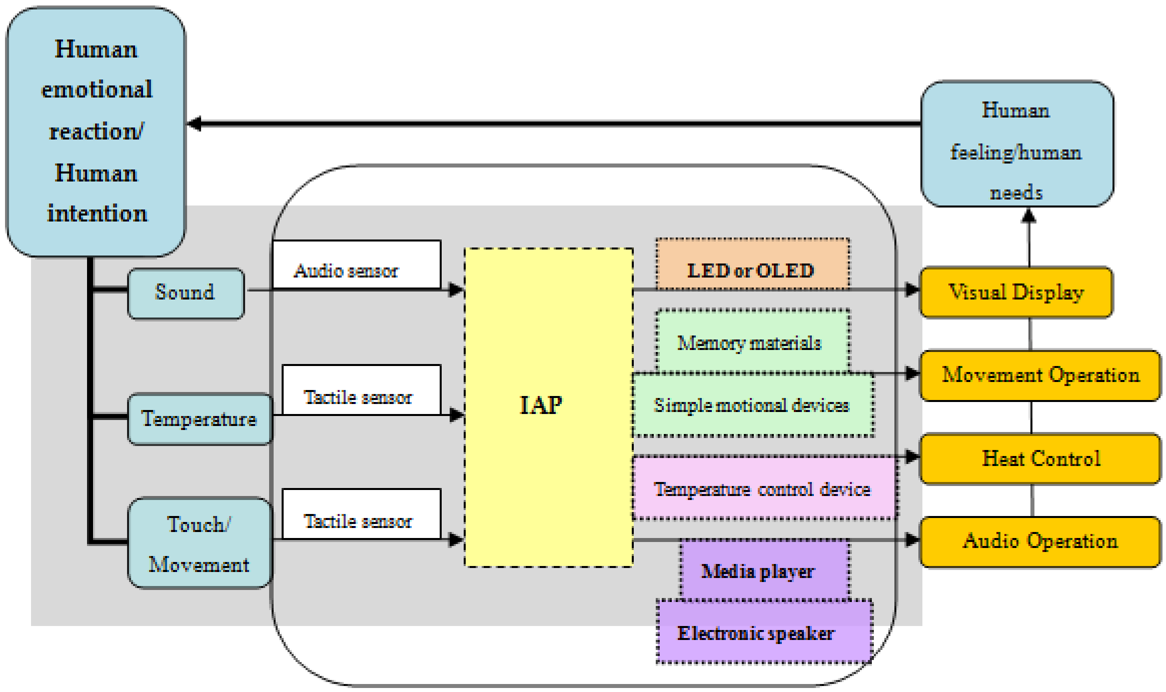


Figure 3-6. Further analysis of the basic interaction process in detail.

Thus, forms that are likely to arise in the course of interactivity can be further summarized and analyzed by combining analysis of the basic process with the relation and levels of interactivity.

According to this project focused on 'Interactive', the next classification with reference to the 'levels of interactivity' will be from 'Interactive' to 'communication'. Using relation 3e (which corresponds to level 3 'interactive') and relation 4g (which corresponds to level 4 'communication') as basic units, further classification of interactivity processes can be presented as simplex type, multiplex type and complex type. The following are specific analyses.

Human ⋧ Interactive artifact [e] – Interactive [I]

Further processes are purposed below:

a. Simplex type (one sense input):

According to the interaction subject program, which sense is to be established and the extent of sense discrimination is worked out. For example, when SOUND is chosen as the input, the form of outputs will vary with frequency change (e.g., sound 1-A, sound 2-A, sound N-A, etc.) detected by the corresponding programs during the input process. See Figure 3-7.

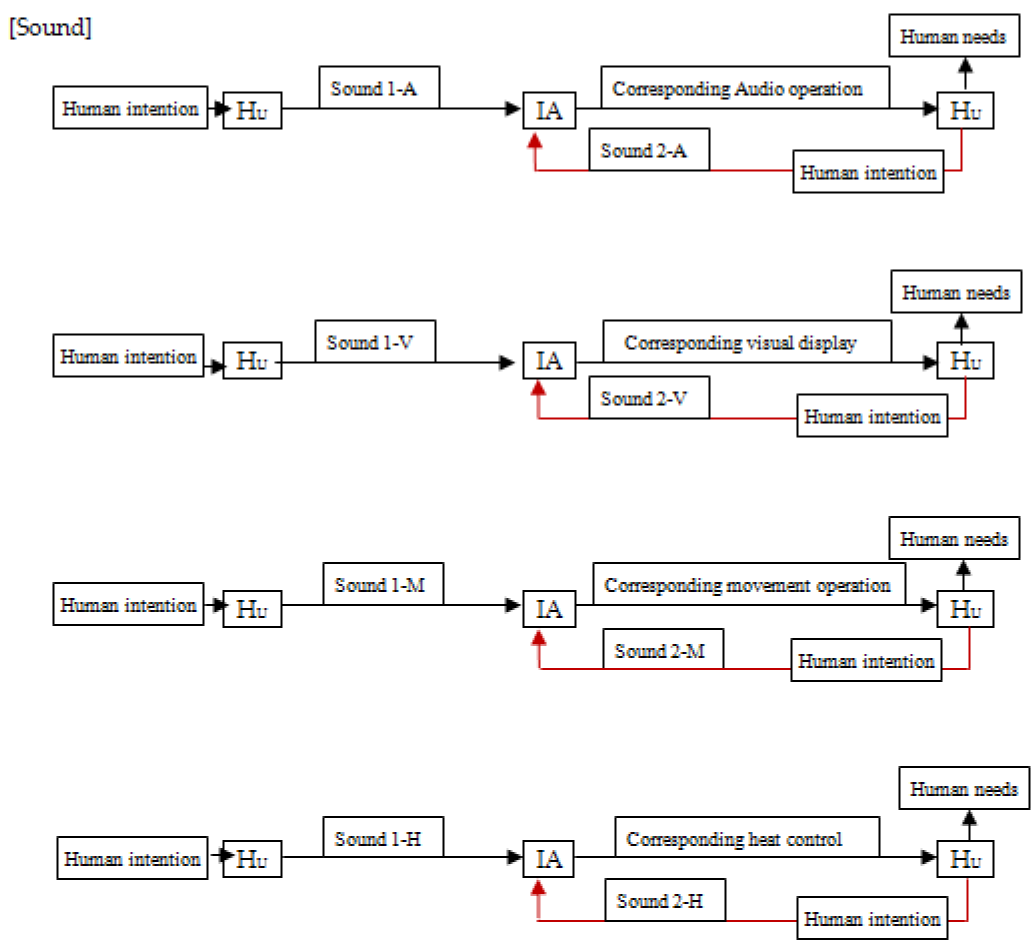


Figure 3-7. Simplex type sample: the interaction process as sound as input.

b. Multiplex Type (several sense inputs):

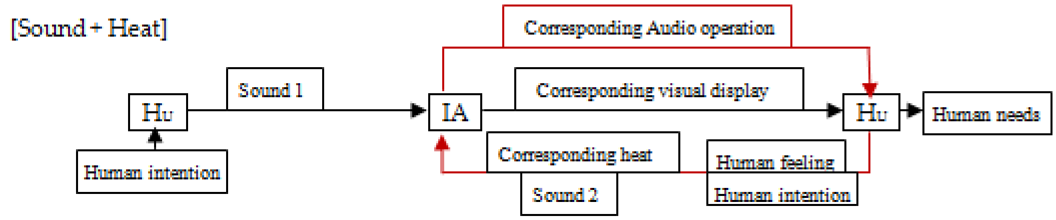


Figure 3-8. Multiplex type sample: the interaction process as sound + heat as input.

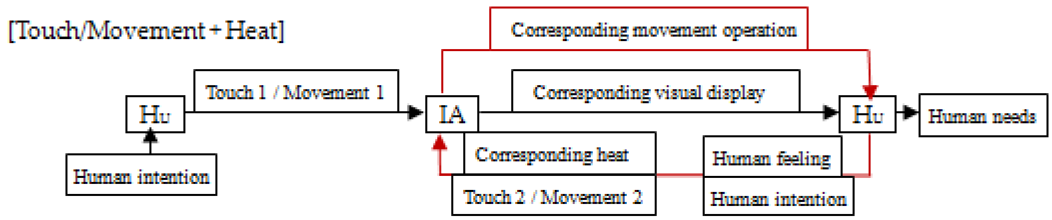


Figure 3-9. Multiplex type sample: the interaction process as touch/movement + heat as input.

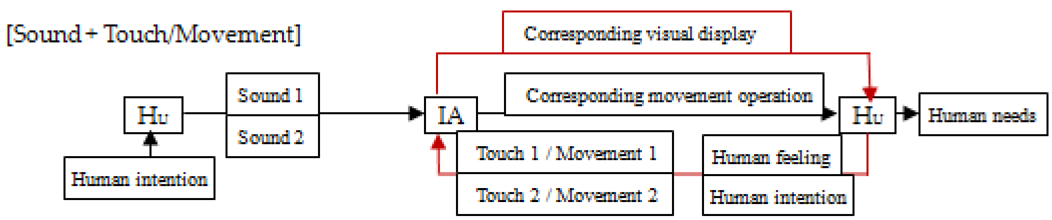


Figure 3-10. Multiplex type sample: the interaction process as sound + touch/movement as input.

Multiplex type refers to the type when IA is able to sense two combined inputs. The possibilities are 'Sound + Heat', 'Touch/Movement + Heat' and Sound + Touch/Movement'. The forms of output will correspond to minute changes in the inputs determined by the program designs of IAP. The circular process continues until intervention is instituted to stop the interactive process.

Human A ⋧ Interactive artifact A ⋧ Interactive artifact B ⋧ Human B [g] – Communicative [C]

c. Complex type (various sense inputs):

c1:

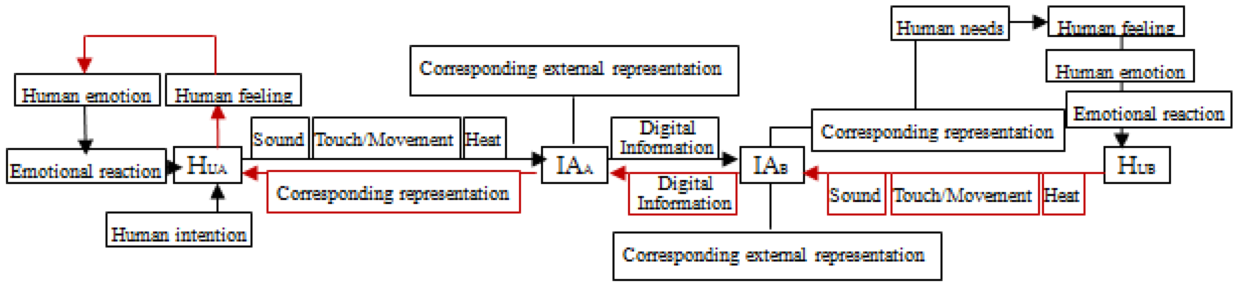


Figure 3-11. Complex type sample: c1.

c2:

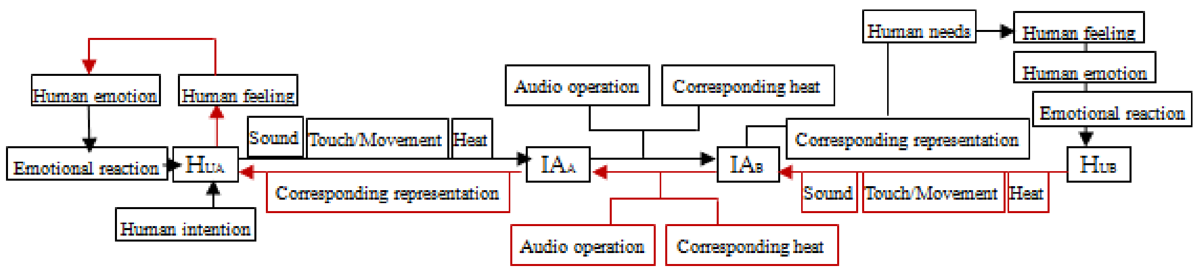


Figure 3-12. Complex type sample: c2.

c3:

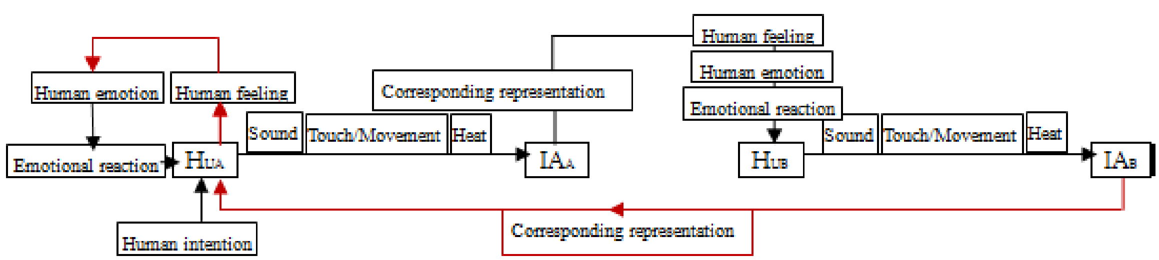


Figure 3-13. Complex type sample: c3.

Further analysis of the highest level of interactivity, i.e., communicative, and its corresponding relation revealed the complex type of interactivity which involves three different types of data transfer and representation. In complex type, IA is able to sense as many as three different forms of inputs at a time, and the IAP determines their corresponding form(s) of output.

3.3 Theoretical System of Interactive Fashion (IF)

Based on the in-depth study of processes and expressive forms of interactivity through the proposed theoretical system and the operational system, the scope of research was narrowed down to analysis of design principles of IF as below.

3.3.1 Definition of IF

FASHION vs. INTERACTIVE FASHION (IF)

- FASHION

The meaning of fashion goes beyond that of clothing. In addition to the basic functions of fashion which are to keep the body warm and to protect it from externalities, fashion is also a language that speaks about personality, taste, emotion, lifestyle and social status of the wearer, i.e., the fashion language. Yet, fashion language is a relatively passive instrument which expresses itself through unchanged and unspoken visual appearance; the fashion language of individual wearers is expressed through a specific visual combination of color, style, pattern, details and accessories (Fred, 1994).

- INTERACTIVE FASHION (IF)

Conventional fashion lacks motility and vitality; the fashion language expression is limited to a single wearing mode. Modern society today demands individuals to change their roles and emotions in tune with needs of different social situations. To this end, a dynamic and changeable fashion language is required. On the other hand, there has been an imminent need to monitor and regulate our psychology and emotions in a society where individuals are under ever-increasing pressures of different kinds. Being a medium of frequent and intimate contact with humans, fashion needs to be enriched with deeper meanings and missions and the ability to activate its fashion language. Thus, the concept of IF is presented, based on these needs. Yet, what *is* IF?

IF is the new fashion language. It is the fashion language that could be expressed at its own initiative. It possesses activeness, self-initiation, motility and reasoning by which direct and visible interaction or communication among fashion, its wearers and others is created.

Expression of activeness: IF is enlivened with liveliness. It is no longer a layer of a still cover that wraps around the body or a kind of fashion language that cannot speak much for itself. With activeness, fashion transforms itself from its introvert being to an expressive extrovert one. IF responds to human emotions such as happiness, sadness and anger, etc., and/or human intentions through the major elements of fashion language like color, pattern and style for simultaneous interactions. Besides color, pattern and style, IF can also use other forms of expressions such as sound and music to express its fashion language. IF delivers fashion language more directly and makes expression more lively.

Expression of reasoning: to a certain extent, IF is like fashion with brains having reasoning ability. From active perception to corresponding responses is a course of reasoning. It reacts with corresponding responses according to various inputs it receives after some kind of consideration in its mind. Thus, the responses it offers are a result of reasoning. The reasoning IF processes literally make fashion language a language that communicates.

Expression of self-initiation: IF changes fashion from totally passive to simultaneously active. Because IF has considerable reasoning power, it can determine its own form and content of responses through its ‘mind’ and it forms interactions and functions of communication ultimately.

Expression of motility: IF is capable of instant reception and reaction. It means that IF can change into appropriate color, pattern or style at once when it becomes aware of human needs by the informs. And, in turn, IF can offer appropriate responses such as sound, temperature and also the traditional elements change immediately when it detects human emotional changes.

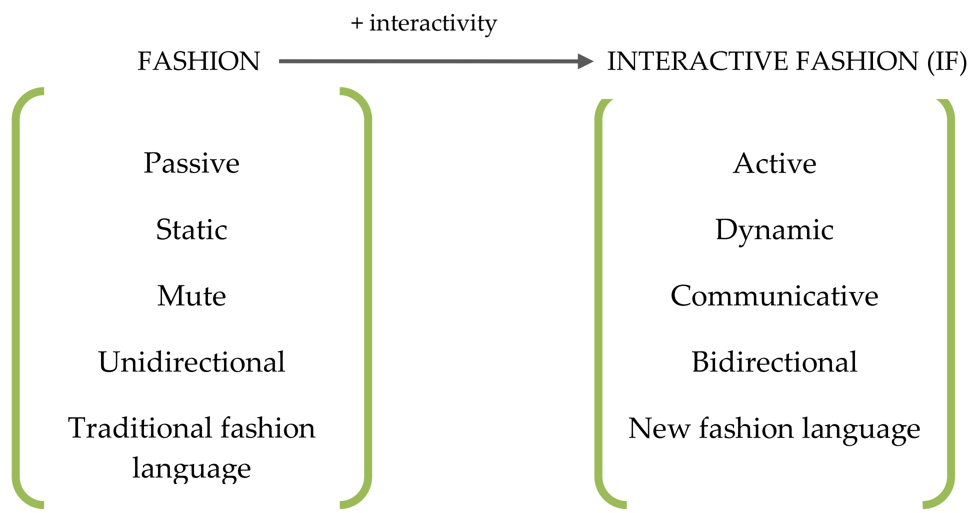


Figure 3-14. Comparison between FASHION and INTERACTIVE FASHION (IF).

With reference to the preceding concept of interactive art, IF attempts to translate ideology into reality, and often in a pragmatic context (Asott, 2003). A brand new form of communication and synthesized fashion language are formed by capitalising on the distinctive characteristics and ideology of Interactive Art in fashion design. Expressing through clothing in a 3-dimensional setting and a 4-dimensional space-time interaction with time, sound, light, text and motion, an infinite range of new forms, relationships and ideas of fashion expressed through fashion (Bullivant, 2007). Like any interaction design, fashion as a design carrier requires injection of new expressive forms to enhance its meaning. It is an integration of traditional designs with the burgeoning ones. Based on the concept of "interactivity", IF often merges electronic engineering and novel materials with fashion, advancing new forms of fashion as a retroaction against the wearer and the observers (Pirhonen, 2005). The original static clothing is vitalized with a multitude of wearing modes, which in turn enrich the expressive forms and artistic contents of fashion during its interactions and exchanges among clothes and people, e.g., between fashion and wearer, fashion and fashion, and wearer and wearer.

Design principles of IF are analyzed below, based on theoretical and operational system of interactivity previously expounded, and in accordance with special requirements and the established limitations of fashion.

3.3.2 Design principles of IF

3.3.2.1 Identification of the key creation elements and requirements

Because of the special requirements and limitations of fashion, the key elements of creative interactive fashion are also bound by certain particularities peculiar to fashion which can be summarized in the following three aspects.

Key creation elements of IF:

- Interactivity

Interactivity is the key pre-requisite of IF. According to the theoretical system of interactivity, levels of interactivity are from 'interactive' to 'communicative' and its relations to interactivity are Relation 3e: Human $\gtrless$ Artifact and Relation, and 4g: Human A $\gtrless$ Artifact A $\gtrless$ Artifact B $\gtrless$ Human A (Section 3.2.2). Since direct contact exists between humans and fashion, the requirement of the level of interactivity is relatively sophisticated. It includes sensibility, responsiveness, and interactiveness in the whole of IA.

- Comfortability

Being the second skin, the comfort of IF is an important index for measuring the merits of its design and quality. Thus, in addition to its interactivity, comfort is another key element of IF. Although IF differs from conventional clothing by its special requirements in terms of fabrics and cut by which interactive activities take place, the simultaneous consideration for comfort makes it difficult to meet its requirements at times. Yet, being an alternative form of fashion that is to be worn, comfort cannot be ignored.

- Aesthetics

Another important element is aesthetics or the visuality of it, i.e., the appearance and construction design. While fully considering interactivity and comfort in the course of design, questions of aesthetic appeal also need to be addressed. For example, how the visuality of IF can perform well and flatter the human body and how the visual aesthetics of fashion as well as the holistic value of fashion can be enhanced through interactive happenings.

After identifying and acknowledging the three key elements in creation of IF, specific practical design requirements were analyzed in detail.

Design requirements of IF:

Based on basic characteristics of fashion and the aforementioned pre-requisites of IF, IF needs to be:

- Flexible

Since IF needs to be worn by humans of complex anatomies who are required to perform various kinds of movements, flexibility of materials and installations used are the first important link in the course of design.

- Small

IF deploys certain extent of electronic, electrical and computing technologies that involve a considerable installation of sensor, chip material, circuitry, wireless devices, etc. However, not all of these devices are compatible with fashion due to the particularity and limitations of fashion. It is preferred for these devices to be small in size in addition to their being flexible.

- Thin

Taking comfort and visuals into consideration, it is desirable for any installation on IF to be thin so that they can be embedded in fabric and/or materials easily.

- Light

Again, it is desirable for the fabric and/or materials of IF to be as light as possible.

Taking the four essential requirements mentioned above, and the need to follow the basic process and the operational system of interactivity, specific devices and materials that are regarded as suitable to be deployed for creation of IF are summarized below.

◆ Input → Sensors

To IA，sensor is the first important link in the whole interaction process chain. It is the pre-requisite for IAP to operate smoothly. The operational system previously introduced summarized briefly but the sensor in standard interaction process, below are the enumeration and analysis of those sensors that are applicable in IF so as to prepare for the initial research and comparative work well for the following stages of design and experiments (Pirhonen, 2005).

Not only should sensors used in interactive fashion fulfill the four design requirements, i.e., small, thin, light and flexible, but they should also have a high degree of sensitivity and good conduction. The table 3-12 below listed the corresponding devices and materials of respective sensors based on influences of the three major inputs, i.e., sound, temperature and touch/movement.

Input Elements	Corresponding Sensors	Specific Devices & Materials
Sound	Audio sensors	Mini audio frequency sensor Mini microphone Mini phase sound sensor Wireless audio sensor
Temperature	Tactile sensors	Heat sensor Temperature detector Fabric sensor
Touch / Movement	Tactile sensors	Pressure sensor Motion sensor Touch sensor Fabric sensor

Table 3-12. Specific devices and materials of corresponding input sensors list.

a. Sound → Audio sensors

Four types of devices that are applicable to design of interactive fashion are listed in the table above. They are: mini audio frequency sensor, mini microphone, mini phase sound sensor, and wireless audio sensor, as shown in Figure 3-15. Among them, wireless audio sensor is of the most applicable value. It is a node of small size and has the capability to process audio signals (Bolton, 2002). Its advantage lies in it being wireless and small in size.

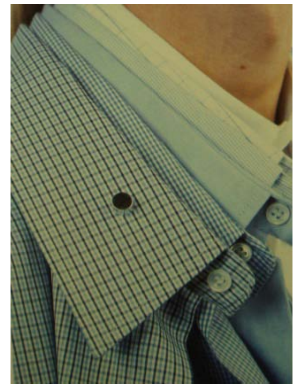


Figure 3-15. i-wear (Walter Van, 2000).

b. Temperature → Tactile sensors

Tactile sensors that detect temperature are generally heat sensors and temperature detectors (Kaptelinin and Nardi, 2006). Both of these devices are able to convey the data of detected temperature change to IAP for internal program processing. Since emphasis is put on the interaction between humans and fashion, sensors here mainly detect temperature of human body.

c. Touch/Movement → Tactile sensors

Another type of sensors is those that can detect touch or movement. Since they have direct contact with humans, these sensors detect heart beat, pulse and the like (Kaptelinin and Nardi, 2006). There are many types of sensors among this category of sensors, including pressure sensors, motion sensors, touch sensors and fabric sensors. These devices or materials can be applied either on the outer layer or inner layer of the garment for detecting the natural operations of human body.

d. Temperature/Touch/Movement → Tactile sensors - Fabric sensor

While fabric sensor is a type of tactile sensor, it is also a kind of smart textile that exhibits characteristics of being flexible, light and thin. It offers a more practical and usable detection platform for IF. Figure 3-16 shows a fabric senor (Lee, 2005). It has a first fabric layer (1701) and a second fabric layer (1702) in physical contact with the first layer. The first layer is knitted as a spacer fabric in which individual spacer threads (1703) extend between a first planar portion (1704) and a second planar portion (1705). The spacer threads insulate threads. The first planar portion and the second planar portion include electrically conducting threads that run in the first direction (1706). The second fabric layer includes conductive threads that run in the second direction (1708). When a force is applied to a region of interaction of the sensor that is greater than a threshold force, the spacer threads at the region of interaction collapse and allows electrical conduction to occur between the first planar portion and the second fabric layer (Lee, 2005).

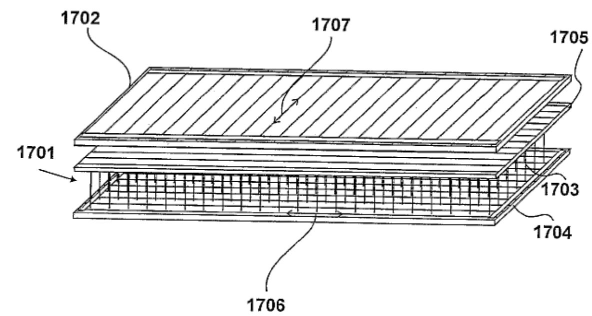


Figure 3-16. Construction of fabric sensor (Lee, 2005).

To date, few researchers have reported results of research on fabric sensors. Below are some examples:

<u>Small sized fiber sensor</u> - This type of sensor has large potential to be used in area of functional wear and smart textiles, such as soft keyboards for wearable electronics, pressure detectors for shoes or belts of clothes and bags. Its advantages state as the fibers used for the design of the sensors has a diameter of only several hundred micrometers; Low cost of material system and fabrication technology is selected and light weight being capable of applications in interactive textiles (Tao, 2007).

<u>Fiber optic sensor</u> - This type of sensor has large potential to be used in areas of functional wear and smart textiles, such as soft keyboards for wearable electronics, pressure detectors for shoes or belts of clothes and bags. Since fibers used for the design of these sensors have diameters of only several hundred micrometers, costs of materials system and fabrication technology are low. They are light weight and capable of applications in interactive textiles (Ghosh, Sarkar and Chakraborty, 2006).

Fabric sensors for three dimensional surface pressure mapping - This type of sensor is applicable in research on human biomechanics in healthcare and clinical medicine areas and in athletics' training to analyze sports data and improve training level. The advantages are high sensitivity and reliability, good flexibility and light weight, long service life and reasonable material costs (Tao, 2007).

Fabric pressure sensor - The sensor from Elek Tex contains a proprietary e-textile that senses pressure. It works by measuring voltage drop across the sensor surface (Elektex Ltd., 2006). Eleksen's textile pressure sensor (see Figure 3-17) has been used in keyboards for mobile electronics as it can be rolled, crumpled or folded without damage (Eleksen Ltd., 2005).

Figure 3-17. Eleksen's textile pressure sensor.

◆ IAP - → Processor →

IAP is the nucleus in IA operation. It conveys the input data detected by sensors for internal processing by designated software to transform input data into output data. Its function is decisive in tranformation of inputs and outputs during which certain transfer channels are required. The type of transfer channel more applicable to interactive fashion is wireless transfer channel such as wi-fi, bluetooth and certain mobile devices. The advantage of these channels lies in their ability to transfer data without wire and that their chip is small in size. However, their disadvantage is having some degree of radiation generated in operations. Thus, anti-radiation materials should be considered in designing these wireless transfer channels (Jones and Marsden, 2006).

Processor Requirements	Specific Software and Microcontrollers
	Hardware: Wireless Transfer Channel: Wi-Fi, Bluetooth, mobile devices, etc.

Table 3-13. The processor requirement of IAP.

Below is the basic proceeding of IAP.

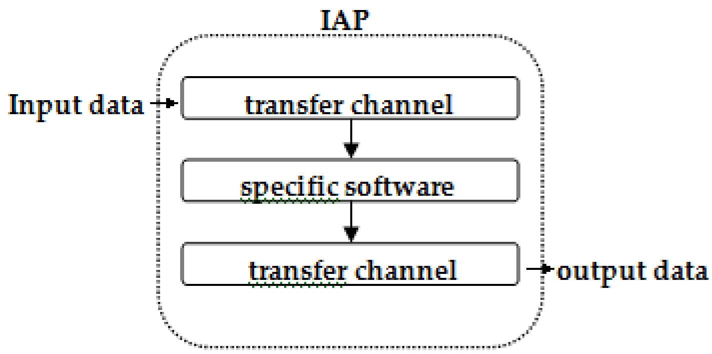


Figure 3-18. The basic proceeding of IAP.

◆ Actuators → Outputs

Output data that have been converted from IAP go through various actuator interfaces and are expressed in various output elements governed by specific software operated by the IAP. Output elements expressed in interactive fashion include vision, sound, temperature and movement. Screened by the aforementioned operational system, the table below lists the corresponding applicable devices and materials.

Output Elements	Corresponding Actuators	Specific Devices & Materials
Vision	Visual actuators	LEDs or OLEDs display Optical fabric
Sound	Audio actuators	Micro loudspeaker
Temperature	Tactile actuators	Micro-chip warming devices
Movement	Tactile actuators	Shape memory materials Simple motional devices

Table 3-14. Specific devices and materials of corresponding output actuator list.

a. visual actuator → vision

Vision is the most expressive element in output. Many applications cited in literature review have used vision of light as the expressive form. It is an important component in the design of output in IF. When visual actuator is used as the platform to express vision output data, normally, various dot matrix displays of LED, OLED are deployed. In this regard, Organic

Light Emitting Diode (OLED) is of particular applicability to IF. Compared with regular LED, OLED is lighter. In addition, polymer LED can have the added benefit of being flexible. OLED is inexpensive and flexible in displays (Graupner, 2000). Optical fabric is yet another option that is equally applicable to fashion. Optical optic fiber is woven into ordinary fibers and functions an important material for facilitating visual display. The sensorial function of optical fiber *per se* provides greater scope for creativity in design because of its ability to carry light.

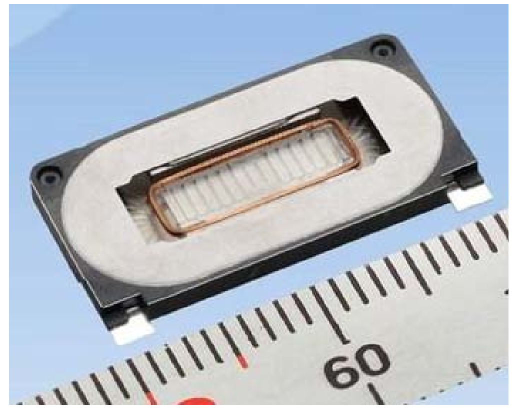


Figure. 3-19. An example of micro loudspeaker chip.

b. Audio actuator → sound

Devices of audio actuator whose output is sound are not particularly complicated. The crux lies in the size and weight. The edge of micro loudspeaker chip lies in its intricate size and shape. An example is shown in Figure 3-19. The dimensions are of 10x20x1.5mm and it weighs less than one gram (NEC, 2006). It is ideal to be used in designing IF.

c. Tactile actuators → Temperature

The main function of tactile actuator with temperature as its form of output is to regulate and release temperature. Normally such regulation is done from within after input from without is detected. Thus, there is no visible change on the surface of IF since such changes are very much a personal experience of the wearer. The temperature output normally takes the form of warming. The technology used is mainly micro-chip warming technology. It has a micro-chip computer which provides safety, consistency and even heat distribution (Buurman, 2005).

d. Tactile actuators → Movement

Due to the limitations in fashion design, changes in movement in IF are normally confined to a lesser degree and frequency. It is also difficult for complicated mechanical devices to be installed. Shape-memory materials are able to fit the characteristics of IF. Shape memory alloy (SMA) and shape memory polymer (SMP) are the more commonly used shape memory materials. Shape memory alloy (SMA) is an alloy that can "remember" and return to its original shape after being deformed, on applying heat to the alloy. When the shape memory effect is correctly harnessed, this material becomes a lightweight, solid-state alternative to conventional actuators (Kauffman and Isaac, 1993). Shape memory polymer (SMP) is polymeric material which has the ability to return from a deformed state (temporary shape) to its original (permanent) shape induced by an external stimulus (trigger), such as temperature change (Lendlein and Kelch, 2002). Both SMA and SMP change their shapes under the influence of temperature change. Besides temperature change, as in the case of thermally activated SMP, a specific SMP can also be activated by an electric or magnetic field, light or a change in pH (Kauffman and Isaac, 1993).

For IF, both possess the characteristic of slight sculpturability, which enables them to be implanted into fabrics. Thus, it is anticipated that a series of feasibility experiments can be carried out in the experimental stage of this project.

3.3.2.2 The basic relations and levels of interaction processes of IF

Summarize relations and levels of interaction process of IF in Table 3-15 below:

<table>
<tr><th colspan="2">Relation</th><th>Level</th></tr>
<tr><td colspan="2">IF→ Environment [a]</td><td rowspan="2">Non-interactive [N]</td></tr>
<tr><td colspan="2">IF → Human [b]</td></tr>
<tr><td colspan="2">Environment → IF → Environment/Human [c]</td><td rowspan="2">Reactive [R]</td></tr>
<tr><td colspan="2">Human → IF → Environment/Human [d]</td></tr>
<tr><td>Human ⋛ IF
[e]</td><td>Subject ⋛ IF
[f]</td><td>Interactive [I]</td></tr>
<tr><td colspan="2">Human A ⋛ IF_A ⋛ IF_B ⋛ Human B
[g]</td><td>Communicative [C]</td></tr>
</table>

Table 3-15. The relations and levels of interaction process of IF.

Sorted by Relation of interactivity:

Relation 1: a. IF → Environment

b. IF → Human

In Ration 1, IF influences environment or human directly through a prescribed course.

Relation 2: c. Environment → IF → Environment/Human

d. Human → IF → Environment/Human

In Ration 2, IF can take in information from environment or human and responds to them. This process is not yet recurring.

Relation 3: e. Human ⇄ IF

f. Subject ⇄ IF

In Relation 3, the interactivity is a recurring one.

Relation 4: g. Human A ⇄ IF$_A$ ⇄ IF$_B$ ⇄ Human B

In Relation 4, the occurrence of interactivity has transformed from direct contact to a more sophisticated interactive course. It can take place through wireless communication, and is recurring.

Sorted by Levels of interactivity

Level 1: Non-interactive	Relation 1:	a. IF → Environment
↓		b. IF → Human
Level 2: Reactive	Relation 2:	c. Environment → IF → Environment/Human
↓		d. Human → IF → Environment/Human
Level 3: Interactive	Relation 3:	e. Human ⇄ IF
↓		f. Artifact ⇄ IF
Level 4: Communicative	Relation 4:	g. Human A ⇄ IF$_A$ ⇄ IF$_B$ ⇄ Human B

The classification of level of interactivity is primarily according to the interactive relationships between artifacts with environment and/or humans, as well as its ability of interaction. It ranges from passive direct transmission of message (non-interactive) to reception of message and response (reactive) to active reception of message and response (interactive) and passive voluntary interflow (communicative).

3.3.2.3 Generalization of the further interaction processes of IF

Design requirements of interactive fashion have been explained in 3.3.2.1 and suitable devices and materials have been identified and described. Based on the data in 'The Further Classification of Interaction Process', this section proposes the interaction processes that specifically addresses to IF.

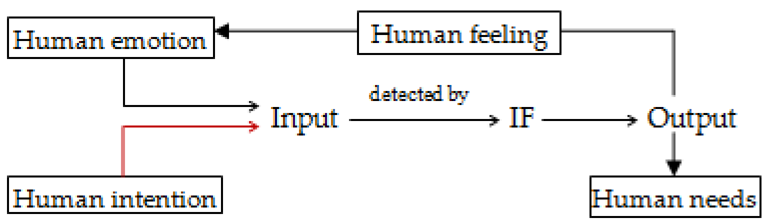


Figure 3-20. The basic interaction process in detail of IF.

The incisive point of analysis of interaction processes is the number of participants in an interaction process and that of IF. Due to the complexity and repetition of interaction, the number of participants and that of IF is both capped at 2. Possible scenarios include:

1. One wearer with one piece of IF;
2. One wearer with one piece of IF and one non-wearer; and
3. Two wearers with two pieces IF.

1. One wearer with one piece of IF:

Using the model in 3.2.2., i.e., Human ⋛ Interactive artifact [e] – Interactive [I], it will be interpreted as:

Wearer ⋛ IF [e] – Interactive [I].

The relation of interaction between one wearer and one piece of IF is proposed to be a circulatory interactive process. It is based on the relation between humans and interactive artifacts. Due to the intimacy between fashion and humans, sensors and sensory systems of a higher sensibility and fitness against human body are required. Since this interaction process is mainly the intimate detection and interaction between the wearer and the fashion, no obvious external form of manifestation is noticed on the IF.

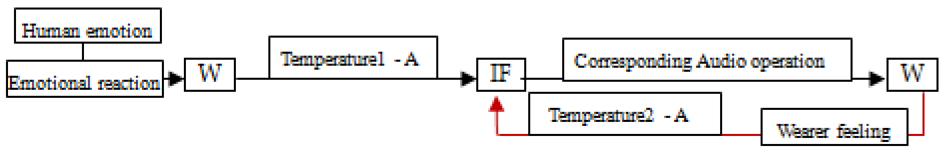


Figure 3-21. The interaction process example.

2. One wear and one un-wearer with one piece of IF:

2a. Non-wearer → IF → Wearer [d] - Reactive [R]

Input in this scenario is the behavior of the non-wearer, conveyed to the wearer through detection mechanism of IF. Here, manifestation of the IF is the internal conveyance; actuators here mainly are spread on the inside of IF.

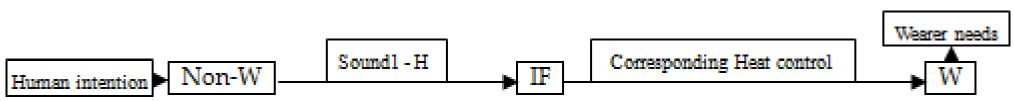


Figure 3-22. The interaction process example.

2b. Wearer ⪌ IF ⪌ Non-wearer [e] – Interactive [I]

In this scenario, the action expressed by the wearer is received as input by the senor installed internally in an IF, and is expressed as the corresponding form of output programmed by the actuator to a non-wearer. The non-wearer will then respond to the output in a certain form of behavior which, in turn, will be received back by the senor installed externally on the IF as input, and is conveyed to the wearer through the actuator installed internally in the IF. This process can be in a loop.

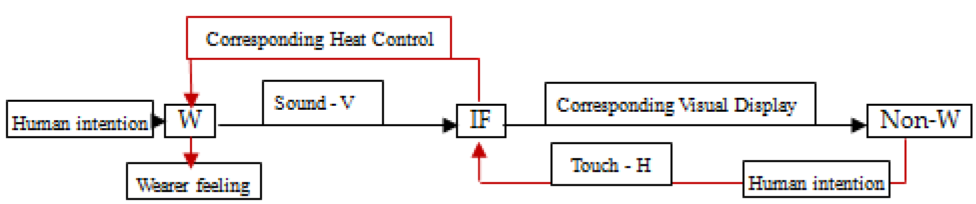


Figure 3-23. The interaction process example.

3. Two wearers with two pieces IF:

Using the model in 3.2.2, i.e., Human A ≷ Interactive artifact A ≷ Interactive artifact B ≷ Human B [g] – Communicative [C], it will be interpreted as:

3a. Wearer A ≷ IF$_A$ ≷ IF$_B$ ≷ Wearer B [g] - Communicative [C]

The first scenario uses the input of Wearer A as the starting point. Here, not only does IF exhibit output externally, but at the same time, IF$_A$ also conveys data to IF$_B$ via wireless transfer channel to further influence Wearer B. Thereafter, Wearer B acts as the starting point of input and a continuous loop of interaction process is formed.

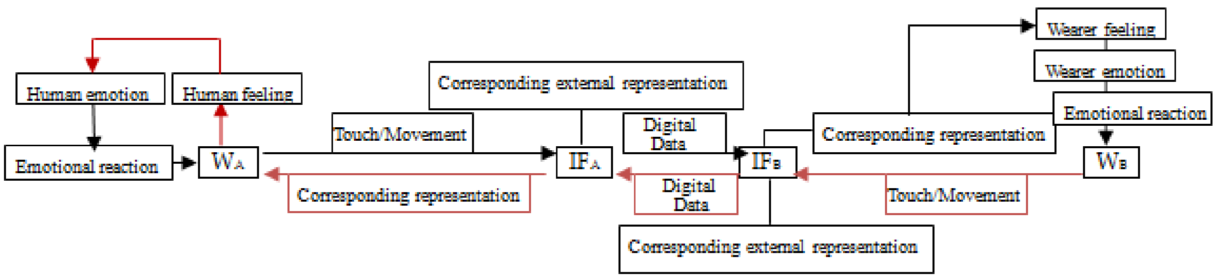


Figure 3-24. The interaction process example.

3b. Wearer A → IF$_A$ → Wearer B → IF$_B$ [g] - Communicative [C]

The difference between the 1st and the 2nd scenario is that in the 2nd scenario, no data transfer is required between IF$_A$ and IF$_B$, the output of IF is determined directly by behaviors and interactions between the two corresponding wearers. Thus, the output of IF in this interaction process is through manifestation of the externally installed actuators.

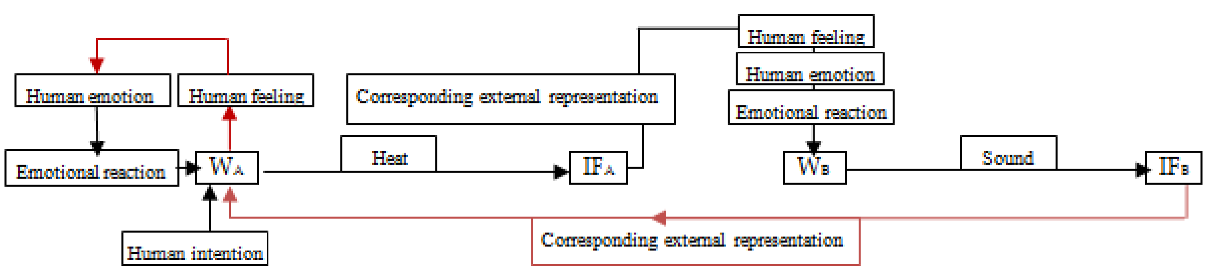


Figure 3-25. The interaction process example.

Analysis of various interaction processes of IF proposed above provides a clear reference for positioning the following design plans and creations.

3.4 Theoretical Basis of Emotional Recognition via Physiological Signal Data towards IF

The IF theoretical system, design concepts and design principles were analyzed. A theoretical system from the macroscopic view was further established to explain IF in detail. This chapter explores the theoretical basis of IF related to emotion recognition and preparations for subsequent specific operations and research.

3.4.1 Theoretical analysis of Emotional Recognition

In interpersonal communication, it is an important part of human emotions and intelligence to recognize the emotional state of others. Research objects of emotion recognition include physical emotion recognition (Essa and Pentland, 1997), speech emotion recognition, semantic emotion recognition (Yang, Meng, Wu et al., 2006), physiological signal emotion recognition (Picard, Vyzas & Healey, 2001), etc. This research was based on IF features and design principles to focus on study and design of IF recognition of physiological signals generated by emotional physiological responses.

3.4.1.1 Definition of emotion

Before conducting research on Emotion Recognition, emotion needs to be understood first. This was a complicated task. Human emotion phenomena are the result of extremely complex integration of physiological and psychological cultures. An attempt to give human emotions precise definitions and descriptions is not an easy task. In the field of psychology, studies on emotion have had a long history, and yet, so far, no consensus definition has been formed.

Paul R. K. and Anne M. K. (1981) summarized definitions of emotions by a number of previous scholars. Most of these definitions are relatively complex, abstract and difficult to understand. Two of these examples are cited below:

Tomkins theory (1962): Emotions, Constitute the Primary motivational system of humans. Each of the Primary emotions Supplies its own unique kind of motivating information.

Plutchik theory (1980): Emotions have an evolutionary history and have evolved various forms of expression in different species. They have adaptive functions for the individual; they need to be inferred from various sources of evidence; they are based on specific cognitions; and they reveal something of an individual's attitudes and motivations."

In addition, Davidson et al. (1999) believe that emotion is a transient physiological and psychological phenomenon that represents behaviors of an individual to adapt to the environment. Scherer and Banziger (2004) reckoned that emotion is reflection of psychological and physiological state of an individual caused by the environment he is in, which differs from the stance, attitude and temperament of the individual. In addition to the concerns for emotion theories, emotion psychology also discloses positive roles of emotions in goal-oriented activities, which has inspired more research on an applied nature to further explore the possibility of using emotion features to practically solve problems. Oatley and Jenkins et al. (2006) proposed that emotion is an exchange of information between people caused by the composition of their behaviors, physiological changes and subjective experiences caused by inner thoughts and external events. According to the discussions of Frijda (2007), emotion is of both an intentional nature and a functional nature: emotion of an intentional nature indicates that its occurrence is associated with a particular object, while that of functional nature is to control actions and give immediate psychological and physiological responses against a specific situation.

In summary, a generally precise definition is: emotion is not just a subjective concept which is subject to societal and cultural influences on an individual; different people have the same emotional expressions under most circumstances. For example, when achieving success, people will mostly feel happy; the degree of happiness is determined by the extent of success and the satisfaction level of individuals. When frustrated, people will mostly be sad. Therefore, researchers have begun to shift their focus from various emotion definitions to general classification methods commonly used to study emotion.

Over the years, basic emotions proposed by various researchers range from two to twenty (Andrew and Terence, 1990). Their views are summarized in Table 3-16 below:

Investigators	Basic emotions
Arnold	Anger，aversion，courage，dejection，desire，despair，fear，hate，hope，love，sadness
Ekman，Friesen & Ellsworth	Anger，disgust，fear，joy，sadness，surprise
Fridja	Desire，happiness，interest，surprise，wonder，sorrow
Gray	Rage and terror，anxiety，joy
lzard	Anger，contempt，disgust，distress，fear，guilt，interest，joy，shame，surprise
James	Fear，grief，love，rage
McDougall	Anger，disgust，elation，fear，subjection，tender，wonder
Mower	Pain，pleasure
Oatley and Johnson-Laird	Anger，disgust，anxiety，happiness，sadness
Panksepp	Expectancy，fear，rage，panic
Plutchik	Acceptance，anger，anticipation，disgust，joy，fear，sadness，surprise
Tomkins	Anger，interest，contempt，disgust，distress，fear，joy，shame，surprise
Watson	Fear，love，rage
Weiner & Graham	Happiness，sadness

Table 3-16. Different points of view of the basic emotions.

Overall, some general emotions exist while other emotions differ greatly. Among these emotions, four are the most common, namely, fear, anger, sadness and pleasure/joy. They are followed by disgust and surprise. Therefore, the above six emotions are widely regarded as the six basic discrete emotions (i.e., fear, anger, sadness, pleasure/joy, disgust and surprise).

3.4.1.2 Models of emotional recognition classification

- Markov Model of Emotion

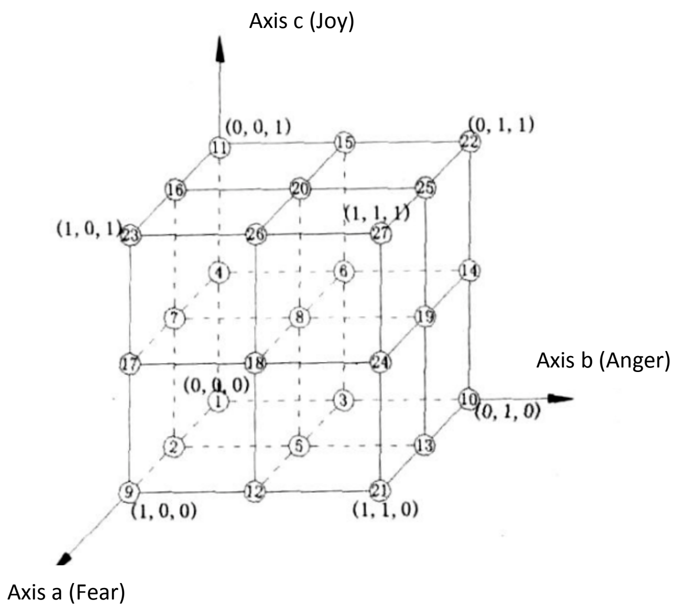


Figure 3-26. Markov Model of Emotion.

The Markov Model of emotion (Figure 3-26) uses the discrete-state isomorphic model to describe people's emotions. A three-dimensional space model taking fear, anger and joy as the dimensions is constructed. Any emotional state can be represented by a corresponding point in the three-dimensional space. Each basic dimension only has three strengths, i.e., the amplitude of each dimension only takes 3 values: 0, 0.5 and 1. If a is used to represent fear, b to anger and c to joy, we will have a (0, 0.5, 1), b (0, 0.5, 1), and c (0, 0.5, 1) (Meng and Wang, 2008). Twenty-seven emotional states can be enumerated and they correspond to the numbers in Figure 3-26. The corresponding detail data is shown in Appendix A.1.

- Plutchik 's Emotion Wheel Model

Plutchik's Emotion Wheel invented by Robert Plutchik (1980) is the most influential classification method of common emotional response. He believes there are 8 kinds of "original" emotional elements - ecstasy, admiration, terror, surprise, sad, disgust, anger and alert. These "original" elements are original physiological elements and they are in constant evolution in order to improve the adaptability of the animal.

The three-dimensional rotating model in Figure 3-27 describes the internal relations among emotions, and each of them corresponds to a color on the wheel. The vertical height of the cone represents the intensity of emotions, and fan-shaped petals with eight tops are designed to explain the dimensions of the eight emotions, with the circle representing different levels of similar emotions. The emotion in the blank part is basic Dyads emotion, i.e., a mixture of two basic emotions (Philip and Ann, 1994).

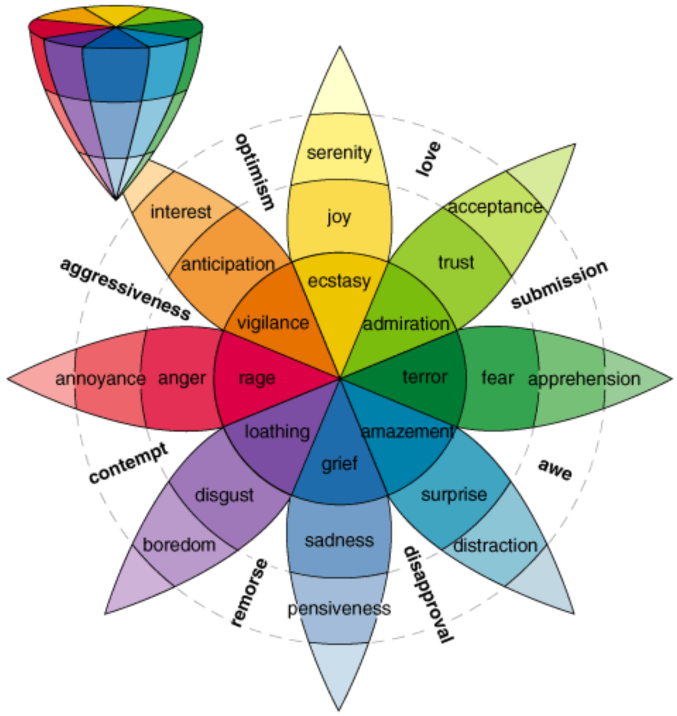


Figure 3-27. Plutchik's Emotion Wheel Model.

- Fox Model

Fox proposed three-level emotion model (Cowie et al., 2001) where different emotions are divided into different levels according to their respective active and passive levels as shown in Table 3-17. The lower the level, the rougher the classification is whereas the higher the level, the finer the classification is.

1st Level	Approach			Withdrawal		
2nd Level	Joy	Interest	Anger	Distress	Disgust	Fear
3rd Level	Pride	Concern	Hostility	Misery	Contempt	Horror
	Bliss	Responsibility	Jealousy	Agony	Resentment	Anxiety

Table 3-17. Fox's 3 Level Emotional classification model.

- The model used by Augsburg University

It is well-known that in model recognition, the more the model types, the more complicated computing is. After considering various emotion models and simplicity of

Emotion

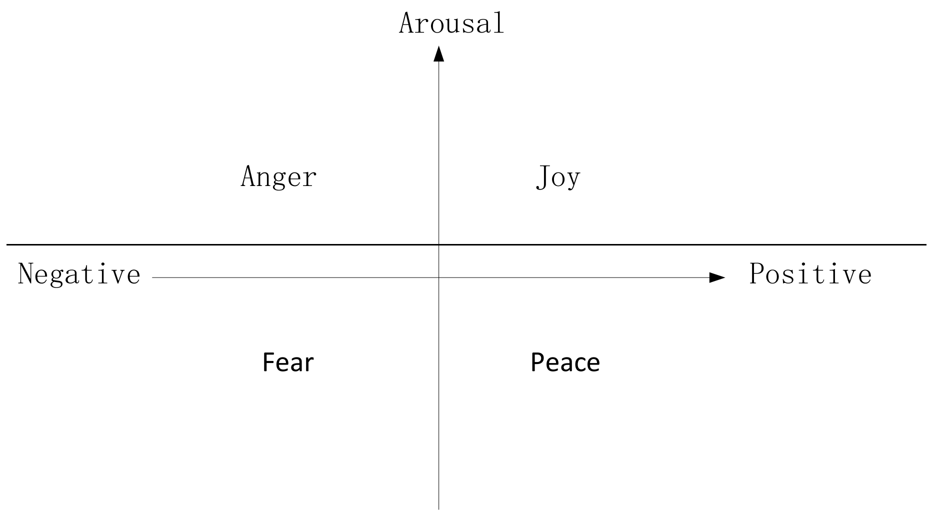


Figure 3-28. The Augsburg's model of emotional recognition classification.

Recognition classifications, the model of emotional recognition classification used by Augsburg University in German in 2005 was selected for the following experiments in this research (see Figure 3-28), hereafter refers to as the Augsburg's model. In the Augsburg's model, Joy and Pleasure are not practically different. Therefore, the four basic emotion states of emotion model in this research are joy, anger, fear and peace located in four quadrants on the plane with positive and negative moods (Positive/Negative) as the horizontal axis and arousal as the vertical axis (Johannes, Joghwa and Elisabeth, 2005). Among the four emotions, fear and anger are considered to be of high arousal since emotion expression is relatively intense, while joy and peace are considered to be of low arousal due to relatively mild expression. According to the above 4 specific emotions, the definition is as follows:

Emotion	Explanation
Anger	A strong and sometimes violent feeling of displeasure, usually leading to a desire to hurt or stop the person or thing causing it
Joy	Great happiness
Fear	an emotion experienced in anticipation of some specific pain or danger
Peace	The state of feeling of happiness or satisfaction resulting from an experience that one enjoys

Table 3-18 The explanations of the emotions in the Augsburg's model.

3.4.2 Investigation of physiological data of emotional reaction measurement for emotional recognition

There exist certain difficulties in studying physiological signal in emotion recognition which is of significant theoretical and practical value. Limb, facial, voice, semantic and other emotion recognitions are more intuitive and they are emotions recognized by taking external appearances of the body as measurements. Thus, inner and real emotional state cannot be observed. Physiological signal, i.e., a bioelectricity, bio-impedance or physiological appearance feature, change in signals generated by human body's internal organs along with emotion changes, can more objectively and readily reflect the current emotional state. Emotional physiological responses in emotional state are reflected by changes in heart rate and intensity on the one hand, and changes in peripheral vascular relaxation and contraction, as well as respiration changes, on the other hand. For example, heart rate is normal in satisfaction and happiness; heart rate accelerates and blood pressure rises in fear or rage; blood vessels volume narrows in sudden panic; and respiration spasms occur in pain and tension. Besides, physiological sensors can be placed on human body in a non-invasive and non-destructive way and can maintain good contact with the body (Schachter, 1964). These advantages make study of emotion recognition based on physiological signals closer to the reality and have greater practical value. The purpose of physiological signal emotion recognition is to identify the corresponding relationship between physiological signal feature vector and emotional state. If physiological signal features of emotions can be clearly or precisely correlate via statistical means, human emotions toward a harmonious human-computer emotional interaction can be effectively identified, which will be of huge commercial value. Professor R.W. Picard offers a variety of commercial applications in one of his articles (1997), such as emotional toys, emotional mouse, emotional spectacles, emotional carpets, emotional CDs, emotional education, emotional detection, etc. Machines with emotion recognition capability, which can detect physiological signals of human body, will be able to timely detect any spiritual pressure drivers, prisoners or patients are experiencing in real time and offer recommendations accordingly. Such a machine can also be used in such areas as health, education, sports, entertainment, polygraph, health assessment, psychological treatment, etc.

Take “Blue Eyes Plan” launched by IBM for an instance. The computer can sense action and behavior of people and offer real-time responses accordingly to interact with the people. If the eyes of a person are staring at the television, the computer will signal to switch the television on. In addition, the company has also developed an emotional mouse which can sense the emotional state of the user in terms of his hand blood pressure and temperature (IBM research, 2009). The Biosensor Table BT2 has been developed by Exmocare. When a person is in emotional tension or is angry, his body undergoes certain physiological changes which are likely to endanger human health. A sudden burst of anger leads to heart rate acceleration, body temperature rise, blood pressure and sweat increase. In order to prevent cardiac accidents caused by sudden emotion changes, Exmocare has invented this watch-shaped bio-sensing gauge which can automatically acquire emotional data of the wearer when it is being worn on his wrist. The emotional state [20] of the wearer can be timely acquired by tracking data of heart rate, heart rate change, skin dryness and wet levels, body temperature, location, etc (Exmovere Ltd., 2007).

At present, physiological signals used for emotion recognition research include such parameters as electrocardiography (ECG), respiration (RSP), blood volume pulse (BVP), skin conductivity (SC), electromyography (EMG) and skin temperature (SKT) and electroencephalography (EEG). The basic knowledge of the five physiological signals is listed below.

- Electrocardiosignal (ECG signal)

In every cycle of human heart beat, sinus generates one electrical excitation which is, in turn, transmitted to the atria and ventricles, according to a certain approach and schedule, arousing excitement of the whole heart, making the heart periodically contract, and promoting blood circulation in the whole body. In each cardiac cycle, there is a certain law that governs the direction, approach, sequence and time of electrical changes in the excitation process of various parts of the heart. This bio-electrical change is reflected on the body surface through conductivity tissue and body fluid around the heart, making various parts of the body undergo regular electrical changes in each cardiac cycle. Recording the heart's electrical charge curve by placing the measurement electrodes on certain parts of body surface is the routine clinical ECG electrocardiogram. The typical ECG is shown in Figure 3-29. Waveform appearing in each cardiac cycle is regular, including a P wave, a QRS wave group, and a T wave. The first wave, which appears slowly, is P wave, representing the excitation process of the right and left atria. The first half of P wave represents right atrium excitation, the middle part represents common excitation of the two atria, and the latter half of P wave represents left atrium excitation. QRS wave group appears next, of which the first downward wave is Q wave, the first upward high and sharp wave is R wave, and the first downward wave after R wave is S wave. QRS wave group represents the electrical excitation process of both ventricles, and the time consumed is the excitation propagation time of the two ventricles. T weave follows QRS wave group. It is low and of long duration. It represents potential impact of ventricular recovery process. The first half of T wave is long while the latter half is short. It mainly reflects the ventricular recovery process after excitability. The part between P wave and QRS wave group is called PQ part, and the part between QRS wave group and T wave is called ST part. In all waves of EC signal, R wave is the most obvious that can be most easily detected. It usually serves as the reference to locate the position of the other waves. Therefore, R wave detection is the premise and basis of ECG signal analysis and diagnosis (Melnik, 2007).

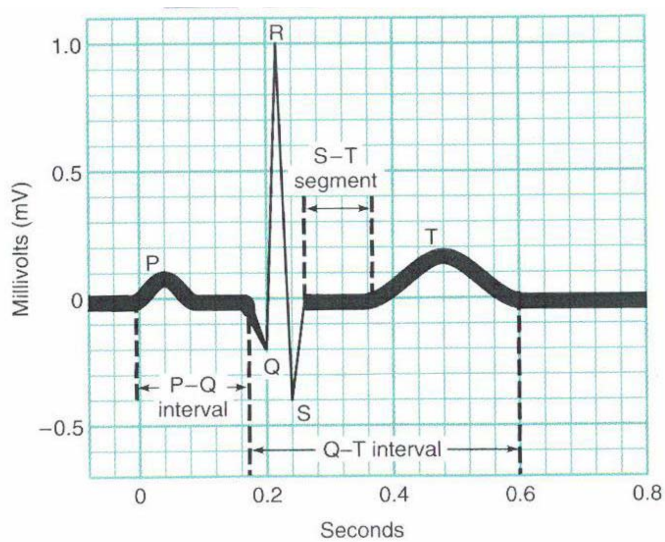


Figure 3-29. Typical ECG signal waveform.

- Blood volume pulse signal (BVP signal)

Blood volume pulse (BVP) signal is a relative index which has no standard unit. Every heartbeat leads to an increase of skin blood flow whereas blood flow decreases in intervals between two heart beats. BVP index indicates vascular relaxation and contraction responses and excitation of sympathetic nerves. Since blood volume (BV) is one of the related parameters affecting cardiac output, pulse associated with blood volume is selected as a parameter (Li, Zhai and Barreto, 2003). Typical BVP waveform is as shown in Figure 3-30.

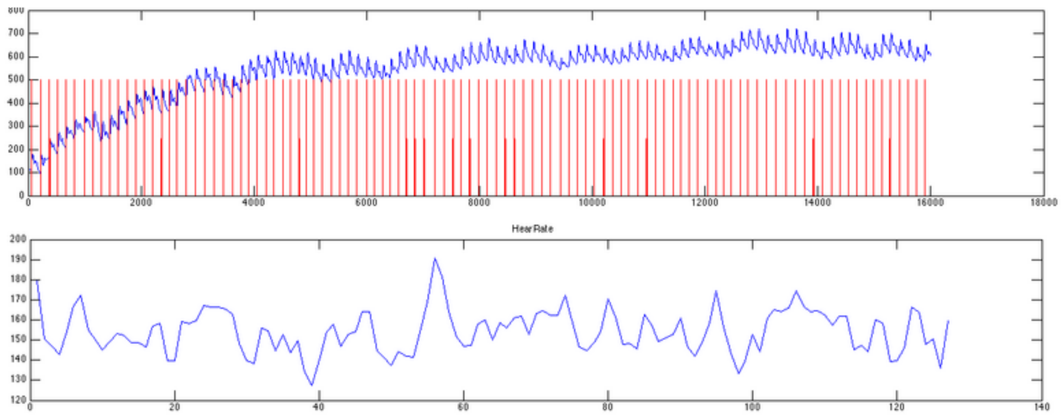


Figure 3-30. Typical BVP signal waveform.

- Respiration signal (RSP signal)

Respiration is the process of gas exchange between human body and the external environment. Through respiration, human body constantly absorbs oxygen from the external environment to supply nutrients to the body, maintain energy and temperature, and excrete $C0_2$ produced during oxidation out of human body so as to ensure normal metabolism. Thus, respiration is an important physiological process of human body. Respiratory signal can be measured by chest expansion and contraction by which respiration frequency and amplitude can be calculated (Se, Dae, Sung, Yong and Lee, 2007).

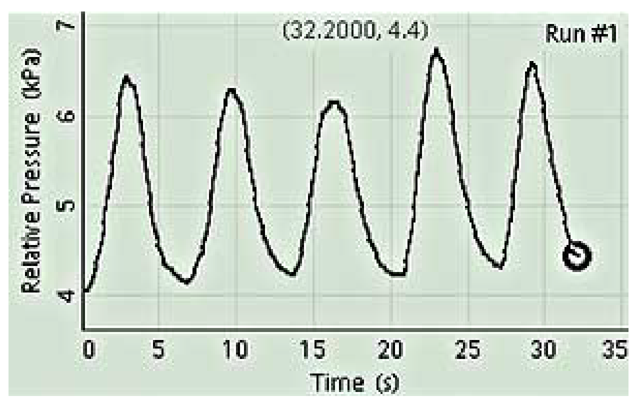


Figure 3-31. Typical RSP signal waveform.

- Electromyographic signal (EMG signal)

EMG is a comprehensive time and space result brought by electrical activity of epidermis muscle on the skin surface. It can be collected through surface electrodes, thus avoiding the trauma brought by piercing needle electrode into muscle. It is a biological electrical signal guided and recorded through the electrode in neuromuscular system actions, and is mainly the combined effect of electrical activities on superficial muscle and neural stem. It has different degrees of relevance with the activity state and functional state of the muscle. Thus, it can reflect neuromuscular activities to a certain extent. Experiments show that electromyographic signal is very weak, with an amplitude of l00~5000uV. Its peak value is usually at 0~6mV and RMS at 0~l.5mv. Generally, useful signal frequency components of electromyographic signals are within the range of 0~500Hz of which major energy is concentrated within 50~150Hz. EMG is a one-dimensional time series signal. It is the result brought by time and space superposition generated when a number of motor units are active while being contacted by surface guide electrode. It is related to such factors as the number of motor units that participate in activities in different functional states and activity states, the discharge frequency of different motor units, the synchronization level of motor unit activity, motor unit recruitment models as well as surface electrode placement position, subcutaneous fat thickness, body temperature, etc. (Luo & Chang, 2010).

- Galvanic skin signal (SC signal)

SC signal is an indication of skin conductivity. A small voltage can be injected between the fingers which is difficult to be detected, skin conductivity can then be measured. Signals are collected by applying voltage on silver chloride electrodes placed on the two tested fingers. To avoid the hand from being bound by the sensor, the same reliable signal can be collected through the electrodes placed on the feet as well. In different emotional states, changes like vessel relaxation and contraction as well as sweat gland secretion inside the skin can cause changes in skin resistance, which can form the basis to determine emotional responses of the autonomic nervous system. In general, galvanic skin signal is related to human emotional arousal. According to the theories of Schachter and Singer (1962), emotions displayed by same physiological signals are different under different arousal levels [40]. Individual differences of electrodermal response basic level is obvious and is related to individual characteristics: the higher the basic level of a person, the more introverted, nervous, anxious, emotionally instable and sensitive he/she is; while the lower is the basic level, the more cheerful, extroverted, mind state balanced, self-confident and psychologically adjustable the person is (Armon, 1986).

3.5 Summary

In this chapter, a theoretical framework of 'Interactivity' as well as an independent theoretical system of IF have been established. Carefully selected and analyzed and reliable theoretical references to serve as the basis for IF design applications are provided. In-depth study identifies tremendous space for potential development of IF in the area of emotion recognition where future design directions can be determined and by which the basic concept of emotion in emotion psychology is elucidated. Classification models for recognizing emotions are identified, and the emotional model to be applied in this research is selected. Application values and methods of different physiological signals in emotion recognition are expounded. Specific implementation and technical issues are further studied and experimented through practical research in the next chapter.

CHAPTER 4

PRACTICAL RESEARCH

4.1 Introduction

The review of previous research studies provided the background to the development of a theoretical framework of Interactivity. Subsequently a theoretical framework for a system applicable to Interactive Fashion (IF) which was related to emotion recognition was devised.

The scope of experimentation for the practice-based component of the research was defined in the light of the theoretical research which was discussed in the previous chapter. The direction for the practical component of the research was then chosen, i.e., the key creative elements and design requirements of IF were defined. Attempts were made to evaluate the different methods using a variety of experiments which were classified according to the following: electronic circuit, method of expression and overall effect. The experimentation process included electronic system design, material test selection, design aesthetics exploration, etc. Operation methods and expression forms were subsequently chosen for IF design and finished products manufacturing in the next phase.

4.2 Appraisal and Further Selection of the Key Creation Elements and Design Requirements of IF

4.2.1 Appraisal

Chapter 3 gave details of the basic input and output elements as well as related materials and devices investigated by earlier researchers. This section elaborates on the key creation elements and design requirements of IF selected for the research under discussion by means of feasibility assessment, including input and output elements, corresponding materials and devices, and IAP requirements. Assessments took into account i) availability/accessibility, ii) complexity, iii) expenses, iv) supportive knowledge base and expertise, and v) technological advancement. The assessment and selection processes were the basis for the ultimate establishment of the forms, relations and levels of the interaction process. The following are the input and output elements, corresponding materials and devices, and IAP requirements which were already summarized and listed in Chapter 3 (Section 3.3.2).

Input elements and corresponding devices and materials of sensors are shown as below:

Input Elements	**Corresponding Sensors**	**Specific Devices & Materials**
Sound	Audio sensors	Mini audio frequency sensor Mini microphone Mini phase sound sensor Wireless audio sensor
Temperature	Tactile sensors	Heat sensor Temperature detector Fabric sensor
Touch / Movement	Tactile sensors	Pressure sensor Motion sensor Touch sensor Fabric sensor

Table 4-1. Specific devices and materials of corresponding input sensors list.

Output elements and corresponding devices and materials of actuators are listed as below:

Output Elements	**Corresponding Actuators**	**Specific Devices & Materials**
Vision	Visual actuators	LEDs or OLEDs display Optical fabric
Sound	Audio actuators	Micro loudspeaker
Temperature	Tactile actuators	Micro-chip warming devices
Movement	Tactile actuators	Shape memory materials Simple motional devices

Table 4-2. Specific devices and materials of corresponding output sensors list.

IAP (→ Processor →) requirements and devices are listed as below:

The processor of Requirements of IAP	Specific Software and Microcontrollers
	Hardware: Wireless Transfer Channel: Wi-Fi, Bluetooth, mobile devices, etc.

Table 4-3. The processor requirement of IAP.

4.2.2 Results of the appraisal and selection

Based on the five conditions of i) availability/accessibility, ii) complexity, iii) expense, iv) supportive knowledge base and expertise, and v) technological advancement, evaluations were made of the following: corresponding sensors against the input elements, corresponding actuators against the output elements, and the IAP requirements to assess ultimately which interaction process forms, relations and levels could be applied in the subsequent IF design. See Tables 4-4 to 4-10.

- Results of the appraisal of input elements

	Mini audio frequency sensor	Mini microphone	Mini phase sensor	Wireless audio sensor
Ⅰ) Availability / accessibility	–	–	±	–
Ⅱ) Complexity	–	–	±	–
Ⅲ) Expenses	–	–	–	–
Ⅳ) Supportive knowledge base & expertise	–	–	–	–
Ⅴ) Technological advancement	–	–	–	–

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-4. Result of the appraisal of input elements – sound – audio sensors.

	Heat sensor	Temperature detector	Fabric Sensor
Ⅰ) Availability / accessibility	±	–	+
Ⅱ) Complexity	±	–	–
Ⅲ) Expenses	–	–	–
Ⅳ) Supportive knowledge base & expertise	–	–	±
Ⅴ) Technological advancement	–	–	–

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-5. Result of the appraisal of input elements – temperature – tactile sensors.

	Pressure sensor	Motion detector	Touch Sensor	Fabric sensor
Ⅰ) Availability / accessibility	+	±	+	+
Ⅱ) Complexity	–	±	+	±
Ⅲ) Expenses	–	–	±	–
Ⅳ) Supportive knowledge base & expertise	±	+	+	±
Ⅴ) Technological advancement	–	–	+	+

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-6. Result of the appraisal of input elements – touch/movement –tactile sensors.

In the appraisal and selection of the input elements (Table 4-4 to 4-6), availability/accessibility was mainly to assess the applicability of such sensors to fashion; complexity was mainly to assess the complexity of sensors applied in fashion; expense was mainly to assess the cost incurred by using such sensors; supportive knowledge base and expertise was mainly to assess the availability of technical support for such type(s) of sensors; and technological advancement to assess the room for development of such sensors in fashion. The above assessments resulted in the selection of the Touch/Movement as the input element. Thus, the corresponding input sensors which were seen as being most suitable for application in the interaction process were pressure sensor, motion sensor and touch sensor.

- Result of the appraisal of output elements

	LED display	OLED display	Optical fabric
Ⅰ) Availability / accessibility	+	–	±
Ⅱ) Complexity	±	–	±
Ⅲ) Expenses	+	–	–
Ⅳ) Supportive knowledge base & expertise	+	±	±
Ⅴ) Technological advancement	+	+	±
Ⅵ) Expressivity	+	+	+

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-7. Result of the appraisal of output elements – vision – visual sensors.

	Micro loudspeaker	Micro-chip warming devices
Ⅰ) Availability / accessibility	−	+
Ⅱ) Complexity	−	+
Ⅲ) Expenses	+	−
Ⅳ) Supportive knowledge base & expertise	−	−
Ⅴ) Technological advancement	±	−
Ⅵ) Expressivity	±	−

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-8. Result of the appraisal of output elements – sound and temperature – audio and tactile actuator.

	Shape memory materials	Simple motional devices
Ⅰ) Availability / accessibility	+	−
Ⅱ) Complexity	−	−
Ⅲ) Expenses	−	−
Ⅳ) Supportive knowledge base & expertise	±	−
Ⅴ) Technological advancement	±	+
Ⅵ) Expressivity	±	+

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-9. Result of the appraisal of output elements – movement – tactile actuator.

In the appraisal and selection of the output elements (Tables 4-7 to 4-9), availability/accessibility was mainly to assesses the applicability of such an actuator to fashion; complexity was mainly to assesses the complexity of such an actuator applied in fashion; expense was mainly to assess the cost of such an actuator; supportive knowledge base and expertise was mainly to assess the availability of technical support for such actuator; and technological advancement was mainly to assesses the room for development of such an actuator in fashion. In addition, expressivity was mainly to assess the external performance strength of the actuator. It was concluded from the above assessments that the most suitable output element was Vision. Thus, the corresponding output actuator which was most suitable for application to the interaction process was an LED display.

- Result of the appraisal of IAP requirements

	Specific software design	Microcontrollers and PCB	Circuit transfer channel	Wireless transfer channel
Ⅰ) Availability / accessibility	+	+	+	±
Ⅱ) Complexity	±	±	±	–
Ⅲ) Expenses	±	±	+	–
Ⅳ) Supportive knowledge base & expertise	+	+	+	+
Ⅴ) Technological advancement	+	+	±	+

N.B. '－' stands 'unsuitability', '±' stands 'neutrality', '＋' stands 'suitability'

Table 4-10. Result of the appraisal of IAP requirements.

In the appraisal and selection of IAP requirements (Table 4-10), availability/accessibility was mainly to assess the applicability of such requirements to fashion; complexity was mainly to assesses the complexity of such requirement in fashion; expense was mainly to assess the cost of such a requirement; supportive knowledge base and expertise was mainly to assess the availability of technical support; and technological advancement was mainly to assesses the potential for development in fashion. It was concluded from the above assessments that the selection of IAP requirements and the corresponding devices which were the most suitable for the interaction process were specific software design, microcontroller and PCB, circuit transfer channel.

The Figure 4-1 below shows the form of interaction process using the results of appraisal and selection of input, output elements and IAP requirements (Section 3.3.2.3) which were suitable for the subsequent IF design.

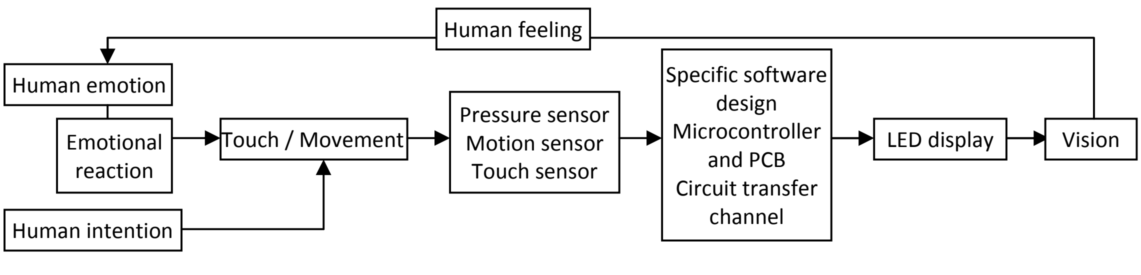


Figure 4-1. The interaction process using the result of appraisal and selection.

The highlight in the below Table 4-11 (section 3.3.2.2) shows the corresponding relations against their respective levels of interaction process in the further IF design.

<table>
<tr><th colspan="2">Relation</th><th>Level</th></tr>
<tr><td colspan="2">IF→ Environment [a]</td><td rowspan="2">Non-interactive [N]</td></tr>
<tr><td colspan="2">IF → Human [b]</td></tr>
<tr><td colspan="2">Environment → IF → Environment/Human [c]</td><td rowspan="2">Reactive [R]</td></tr>
<tr><td colspan="2">Human → IF → Environment/Human [d]</td></tr>
<tr><td>Human $\gtrless$ IF [e]</td><td>Subject $\gtrless$ IF [f]</td><td>Interactive [I]</td></tr>
<tr><td colspan="2">Human A $\gtrless$ IF_A $\gtrless$ IF_B $\gtrless$Human B [g]</td><td>Communicative [C]</td></tr>
</table>

Table 4-11. The corresponding relations and levels.

4.3 Explorations and Experimentations of Electronics on IF

Electronics were important to this research on the subject of IF design. In Chapter 2, electronic technology and wearable electronics were introduced, and in Chapter 3, physiological data for emotional recognition was theoretically overviewed. The research reported in this chapter is based on the result of appraisal and selection in the previous chapter to conduct experiments and compare the findings with those supplied by other researchers.

4.3.1 Collection of physiological signal data of emotional reactions

In this study, emotional recognition was based on the physiological data measured when an emotional reaction was generated. An emotional reaction infers a series of physiological changes during emotional activities, and these physiological changes can be recorded as physiological data via specific instruments for other research purposes. The relationship between emotional reactions and physiological data was explained in detail in section 3.4.2, with reference to five basic emotion physiological responses and their corresponding physiological signals. Since heart rate is the same as pulse rate under normal circumstances, they were combined together (Clifford, 2002). The list is as shown in the following Figure 4-2:

Emotional reaction	Physiological signal data
Heat rate/ pulse rate	ECG/BVP
Neuromuscular motion	EMG
Respiration	RSP
Dermal resistance	SC

Figure 4-2. Selected emotional reaction and physiological signal data.

Based on the previous feasibility assessment, two of the emotional reactions were selected in this study to measure and collect the corresponding physiological data, i.e., heat rate/pulse rate and respiration, and their corresponding physiological data were ECG signal data/BVP signal data and RSP signal data (highlighted in yellow). Below is basic waveform figure of an ECG signal and an RSP signal (Clifford, 2002).

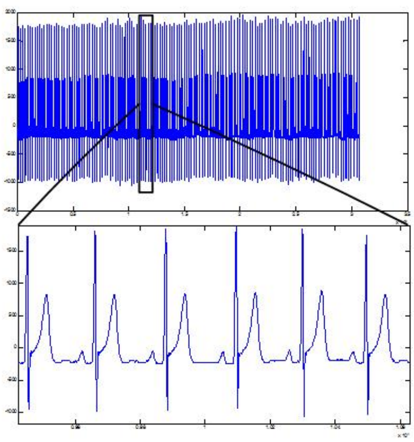


Figure 4-3. Basic EGC waveform.

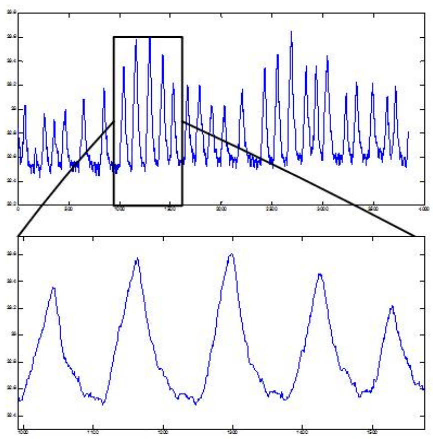


Figure 4-4. Basic RSP waveform.

In this study, the experimental procedure for the collection of emotional and physiological data made reference to the experiments conducted in University of Augsburg in Germany. (Jonghwa, 2005). Forty males and female subjects aged 20-30 were invited to watch four different types of movies, i.e., they signaled joy, anger, fear and peace. The physiological signal data samples of the corresponding subjects were measured using special equipment and the aim of the experiment was to establish an emotion model.

- Electrocardiography (ECG) Measurement – Heartbeat

An Electrocardiography (ECG) signal serves to monitor the heart rate, and is produced by cardiac cells when a human heart beats. It can also reflect the physiological changes of a human heart over time. Ekman et al. (1984) discovered that the heart rate is the fastest when one is in a state of anger and fear; when happy, the heart rate is moderately fast, yet the heart rate slows down when the subject is in a state of sadness of surprise, and the heart rate is at its lowest when the subject experience disgust. In addition, heart rate changes are affected by both gender and emotions, for example, the heart rate of female subjects has been found to be higher than that of male subjects [8]. Lower heart rate variability (HRV) indicates a relaxed state, while the enhanced HRV indicates a possible spiritual state of tension and setbacks (Clifford, 2002).

The measurement process:

1. Subject sits quietly. Glasses, watch, cell phone and other electrical appliances are removed, and all muscles relaxed.
2. Control buttons are placed on the ECG panel on the appropriate location according to the requirements. Any ECG input interface is connected to the ECG guide electrode and the ECG channel connected to a computer acquisition system which records the ECG of the human body. The power is connected after the ECG machine or computer has been properly grounded.
3. Electrode placing: First, the parts where electrodes are to be placed are cleaned using alcohol-soaked cotton balls. The parts with conductive paste are then coated to reduce skin resistance. Electrode holders are placed in positions with less muscle. In general they are positioned about 3 cm above the wrist (flexor side) or 3 cm above the inner ankle.
4. Lead wires connection: lead wires are correctly connected according to provisions of ECG. Generally, lead cords of 5 different colors connect with electrodes of corresponding body parts.
5. Baseline adjustment devices are adjusted so as to place the baseline in the appropriate location.
6. Standard voltage input: when the input switches are opened, the working status of the ECG is adjusted, and the standard voltage (1mV = 10mm) applied.
7. The ECG is then recorded.

The Figure 4-5 shows the ECG measurement of a subject tested.

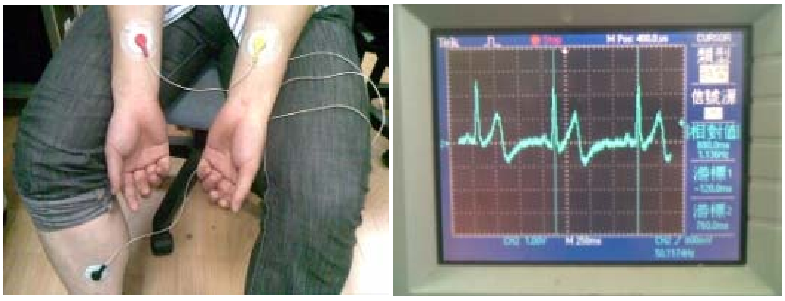
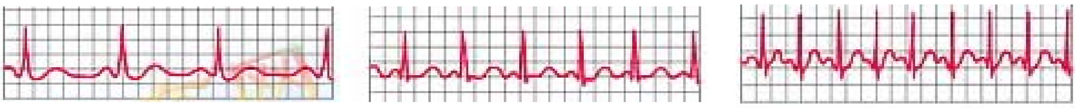


Figure 4-5. ECG measurement of a subject tested.

Figure 4-6 show the normal heartbeat waveform, slow heartbeat waveform and fast heartbeat waveform which were measured via ECG.



Slow heartbeat **Normal heartbeat** **Fast heartbeat**

Figure 4-6. Slow, normal and fast heartbeat ECG waveform.

- BVP measurement – Pulse

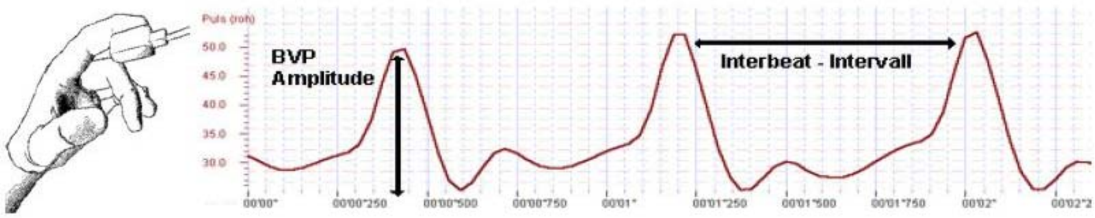


Figure 4-7. BVP measurement method and waveform sample.

The Blood Volume Pulse (BVP) measurement procedure was relatively simple. As shown in Figure 4-7, BVP sensor was positioned close to the skin on the finger, then the red light was emitted from the sensor on the skin surface. The size of the beam of the reflected red light, which changes with the change of subcutaneous blood flow, can be calculated. The real-time BVP waveform measured was shown when it was connected to corresponding monitoring devices. The BVP signal reflected the pressure of the pulse. When a subject is surprised, scared or excited, the signal envelope tends to squeeze tight; while when the subject is relaxed, blood flows to the peripheral and BVP amplitude increases. Blood volume is one of the parameters affecting cardiac output, thus pulse associated with blood volume was adopted in the selection of parameter. Pulse signal is relatively weak. For normal adults, the frequency of the pulse signal is within range of 0.01-40Hz of which 99% of the energy is distributed between 0.01-10Hz (Peter, Harvey and Tyloval, 2007). Figure 4-8 shows one kind of BVP sensor and the measurement situation of one of the subjects tested.

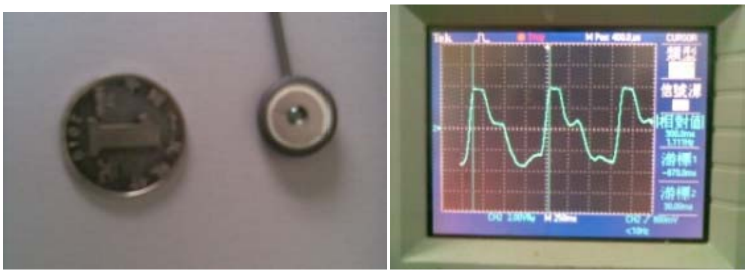


Figure 4-8. BVP sensor and the measured waveform of a subject tested.

- RSP measurement – Respiration

Measurement of RSP is through measurement of chest circumstance. Respiration will cause some slight changes in the chest. The chest expands when the lungs inhale air and contracts when they exhale to discharge air, then the cyclic process repeats. In general, there should be periodically regular ups and downs, as shown in Figure 4-9 below.

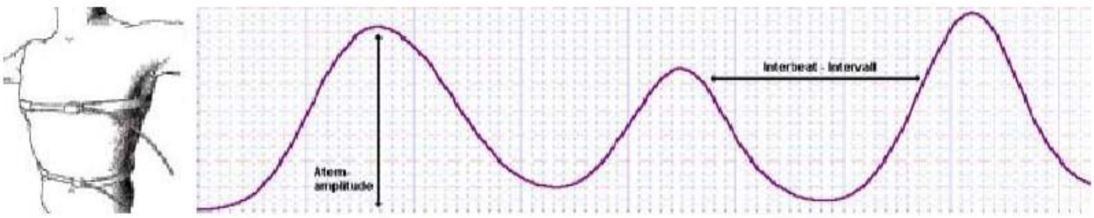


Figure 4-9. RSP measurement method and waveform sample.

The RSP signal changes in speed and depth with the changes in the person's emotional state. An emotional reaction of agony usually accelerates and deepens respiration, while sudden panic will temporarily interrupt respiration, and both ecstasy and sorrow trigger respiratory spasms. In general, the RSP signal frequency range of a normal adult is 0-0.35Hz, and the respiratory rate is 16-20 beats per minute (Joghwa and Elisabeth, 2009). Figure 4-10 shows one kind of RSP sensor and the RSP waveform of a subject in the test.

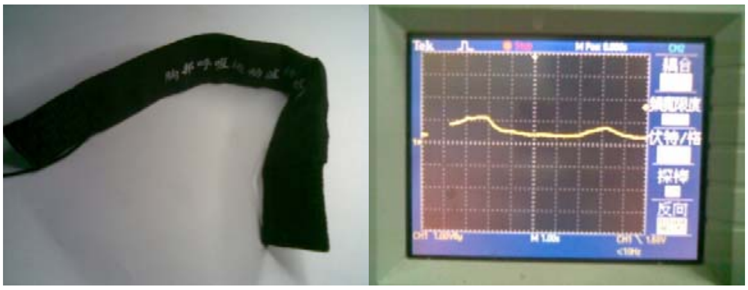


Figure 4-10. RSP sensor and the measured waveform of a subject.

The length of the three physiological signals is 2 minutes each, of which the ECG sampling rate is 256Hz, while the BVP and RSP sampling rates are 64Hz. Figure 4-11 shows a typical physiological signal under four emotion states (Joy, Anger, Fear and Peace).

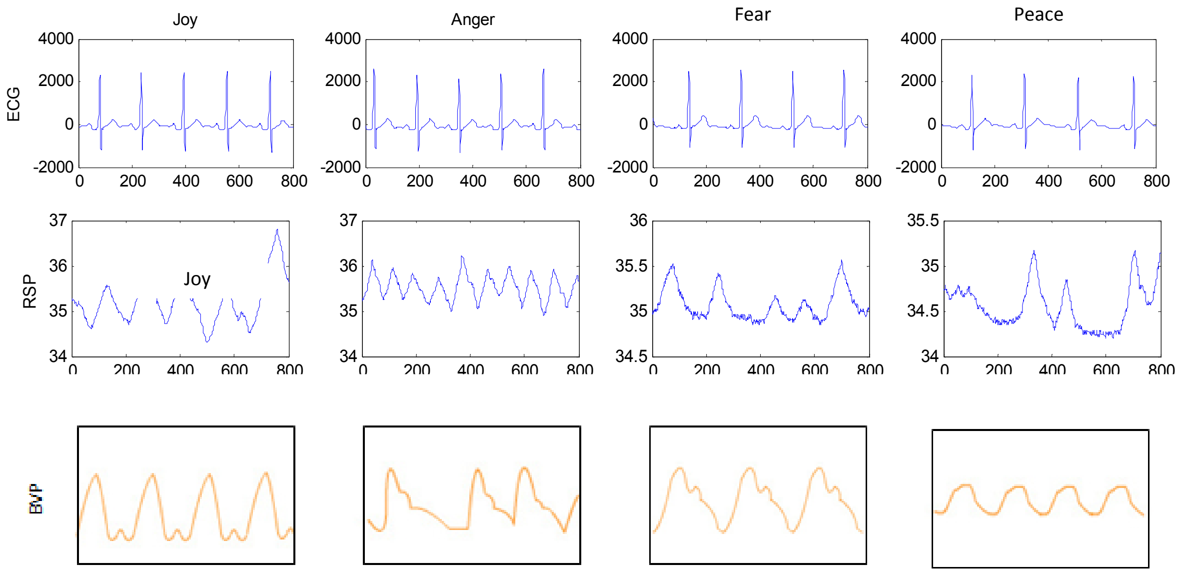


Figure 4-11. The three physiological signal waveforms comparison of one subject under 4 emotions

4.3.2 Feature extraction of collected physiological signals data

Feature extraction from data is based on statistical significance, with the mathematical expressions of feature (Jonhannes, Joghwa and Elisabeth, 2005) being as follows:

1、Normalization

$$\tilde{X}_n = \frac{X_n - \mu x}{\sigma x} \quad \cdots\cdots (4.1)$$

2、Mean value

$$\mu x = \frac{1}{N}\sum_{n=1}^{N} X_n \quad \cdots\cdots (4.2)$$

3、Mean square deviation

$$\sigma x = \left(\frac{1}{N-1}\sum_{n=1}^{N} (X_n - \mu_x)^2 \right)^{\frac{1}{2}} \quad \cdots\cdots (4.3)$$

By applying the above mathematical equations, fifteen features were extracted from the ECG signal, fifteen features from the BVP signal, and ten features from the RSP signal. Figure 4-12 shows the composition of the selected features.

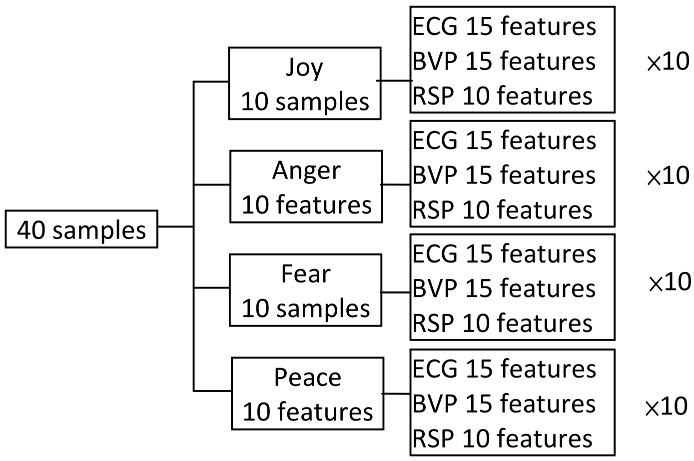


Figure 4-12. Feature matrix.

One sample was extracted each time, and the remaining samples were used to build a classifier SVM1 (Larry and Malik, 2001) to distinguish positive and negative emotions. The ultimate emotion was further recognized by classifying the measured results through SVM2 (Joy/Peace) or SVM3 (Anger/Fear) (Larry and Malik, 2001).

Figure 4-13 shows the Binary Tree Method (Mehta and Sartaj, 2004) of extraction. Binary Tree Method is to classify all types into sub-classes and then further divide sub-classes into two sub-categories, and the cycle continues until a single category is obtained, hence a binary tree is acquired. SVM1 in the figure can distinguish the large group of Joy/Peace from the large group of Anger/Fear, so can emotion arousal degree. The experiment results were obtained by this extraction method.

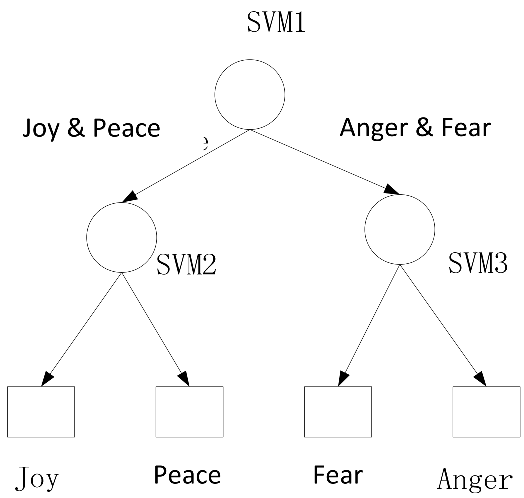


Figure 4-13. Binary tree method emotion recognition diagram.

Experiment results:

Based on the previous experiment planned, Forty subjects (20 males and 20 females) were invited to watch movies which provoked the following four emotions of joy, anger, fear and peace to collect the physiological signal parameters (heartbeat/pulse and respiration) of corresponding emotional reactions of these subjects when they were watching specific footages of the different types movies.

Joy	Anger	Fear	Peace
M1	M2	M3	M4

Table 4-12. Different emotional types movie materials.

Three physiological signals of the tested subjects were taken after they had watched the movies for 2 minutes. According to the experimental analysis, the subjects who had been watching *M1* (representative of joy), had an average heart rate/pulse rate fluctuation range of 70-80 times/minute, and the average respiration fluctuation range was 16-20 times/minute. Those who watched *M2* (representative of peace), had an average heart rate/pulse rate fluctuation range of 70-75 times/min, and the average respiration fluctuation range was 16-18 times/minute. Those who watched *M3* (representative of anger) had an average heart rate/pulse rate fluctuation range of 85-92 times/minute, and the average respiration fluctuation range was 20-25 times/minute. Those who watched *M4* (representative of fear) had an average heart rate/pulse rate fluctuation range of 90-110 times/minute, and the average respiration fluctuation range was 23-28 times/minute. From these results, it can be seen that when experiencing positive emotions, i.e., joy and peace, the features of heart rate/pulse rate and respiration were relatively stable. Conversely, when the emotions were negative, i.e., anger and fear, heart rate/pulse rate were subject to great fluctuation and they accelerated suddenly and markedly, in addition to which, the respiration fluctuation was great a and the shortness of breath significant. Table 4-13 below shows the incorporation of the model of emotional recognition classification via feature extraction of collected physiological signals data.

Emotion states		**Positive emotion** **Joy – Peace**	**Negative emotion** **Anger - Fear**
Physiological signal data of emotion reaction	Variation of Heartbeat rate and waveform	Heartbeat rate range: 70-85 times / min Waveform: regular and stable	Heartbeat rate range: more than 85 times / min Waveform: irregular and unstable
	Variation of Respiration rate and waveform	Respiration rate range: 16-20 times / min Waveform: regular and smooth	Respiration rate range: more than 20 times / min Waveform: irregular and unsmooth

Table 4-13. The incorporation of model of emotional recognition classification.

The results of the experiments performed in order to collect data representative of emotional reactions and physiological signal data were applied in the following electronic system design.

4.3.3 Electronic system design

4.3.3.1 Hardware design

The system hardware included input physiological signals conditioning, signal sampling, data transmission and storage, real-time clock, LED display, etc. The entire electronic detection system is shown in the block diagram in Figure 4-14 below. The physiological signals being detected via this system were BVP, ECG and RSP.

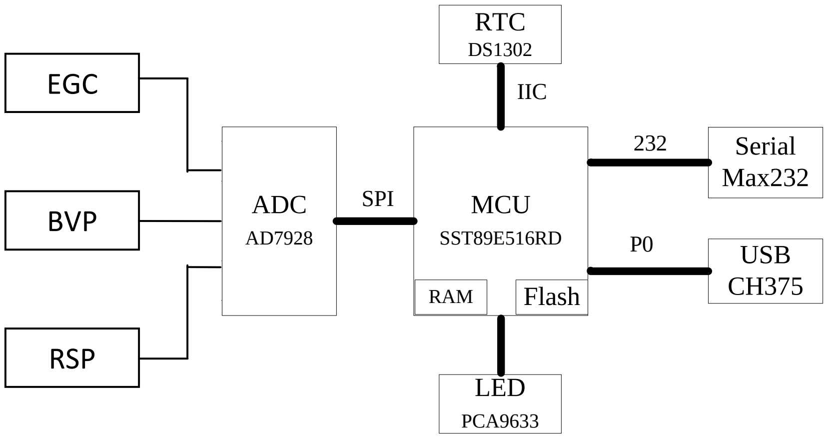


Figure 4-14. Electronic detection system diagram.

The following two modes were supported by the hardware system. In different applications, writing their respective programs using the same hardware platform can permit the instant switchover of these two modes:

- On-line detection mode: when the system is connected to the upper computer, the measured physiological signals were sent in real time to the upper computer through the serials, the current emotion was sent back to the lower computer after emotion recognition, and the corresponding LED lights were then driven to display the current emotional state.

- Off-line measurement mode: when the system was not connected to the upper computer through serials, real-time physiological signals and clock information were recorded by the system and data transferred via the flash memory disk into the upper computer intermittently.

I. Power system

For reasons of portability the measurement system used two 1800mAh batteries for power supply, dividing the whole power into the analog and the digital parts. Power was first connected to the analog signals; design took the central tap of the two power connection points as analog ground (AGND) to achieve positive and negative analog power supply. The power supply for the digital circuit was acquired by connecting a 100uH inductance from +5 V analog power supply, i.e., VCC. See Figure 4-15 (Khandpur, 2005).

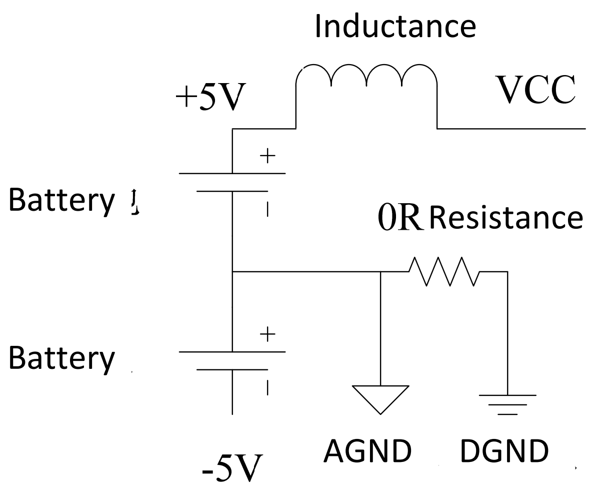


Figure 4-15. Power system circuit diagram.

II. Conditioning circuit of physiological signal

- BVP measurement

A BVP signal reflects the pressure of the pulse. Pulse is pulse wave of aortic root caused by artery expansion and retraction which is further caused by contraction and relaxation of each cardiac cycle. This pulse wave transmits to arteries in the body along the arterial wall. Research has shown that, when a subject is surprised, scared or excited, the signal envelope tends to squeeze tight whereas when he is relaxed, blood flows to the periphery and the BVP amplitude is increased. Pulse signal is relatively weak. For normal adults, the frequency of the pulse signal range is 0.01-40Hz in which 99% of the energy is distributed from 0.01 to 10Hz (Li. Zhai and Barreto, 2003). In order to restrain exercise, noise, contact noise, etc., an integrated photoelectric pulse sensor, i.e., a MB-5B photoelectric finger movement pulse wave sensor, was used, the frequency responses of which were all below 35Hz and the output could reach 1-3.5Vpp. The detailed BVP measurement system circuit diagram is shown in Appendix A.2.1. The sensor output signal can effectively filter out power frequency and exercise, contact noise through the 50mHz-20Hz first-order band-pass filter. See Figure 4-16 for frequency features of band-pass filter.

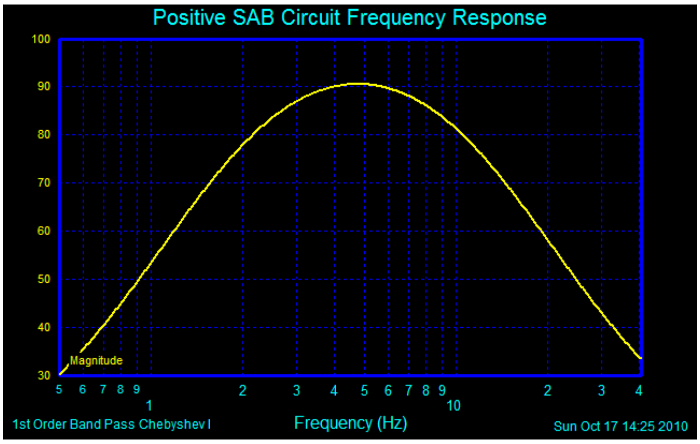


Figure 4-16. Frequency features of filter of BVP measurement.

- ECG measurement

ECG presentation has been described in 4.3.1. In general, a typical ECG signal is of mV-level signal and its frequency range is 0.05-100Hz, of which 90% of the energy of ECG frequency spectrum is concentrated within 0.25-35Hz. QRS wave group energy is concentrated within 3-40Hz, while P and T wave energy is mainly within 0.5-10Hz (Melnik, 2007). The design first used an instrumentation amplifier and an OP97 to constitute the ECG detection circuit. Strong ECG signals were collected through externally-connected leads, and usable signals could be obtained after the signals had passed a band-pass filter with a gain of 200. The detailed EGC measurement system circuit diagram is shown in Appendix A.2.2. The frequency feature of band-pass filter is shown as Figure 4-17.

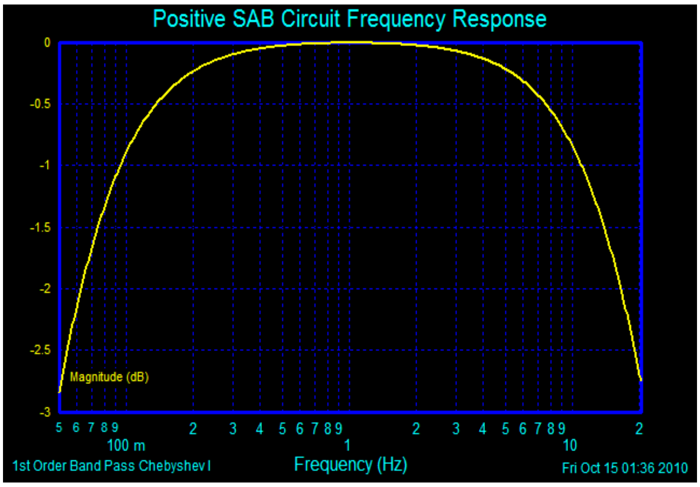


Figure 4-17. Frequency features of filter of EGC measurement.

- RSP measurement

The RSP form of measurement was introduced in section 4.3.2. It reflects respiratory rate and depth and its frequency range is 0-0.35Hz. The general respiratory rate of a normal adult is 16-20 beats per minute (Jonghwa, 2005). The tensile force changes of chest contraction could be detected when sensors were fixed to the chest and abdomen of a subject. Its output was directly proportional to respiration depth. The respiratory signal output was first amplified by 25.6 times by the conditioning circuit. The detailed RSP measurement system circuit diagram is shown in Appendix A.2.3. The RSP signal could effectively remove power frequency interference and interference of high frequency myoelectricity through a low pass filter with a cut-off frequency of 8Hz after the difference amplifier. Frequency features of the filter are shown in Figure 4-18.

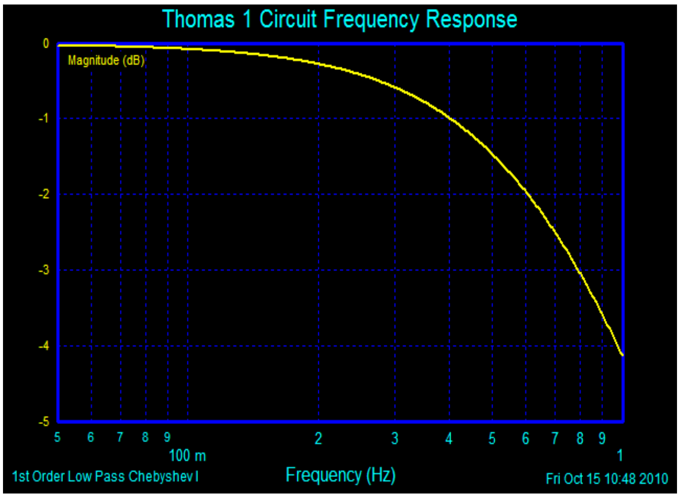


Figure 4-18. Frequency features of filter of RSP measurement.

III. ADC circuit

The previous section introduced in detail features and a conditioning circuit for the three physiological signals to be collected. A summary is shown in Table 4-14 below. The ADC circuit discussed in this section was selected after consideration of the features of these three signals and the special nature of intelligent fashion.

	BVP	ECG	RSP
Frequency range（Hz）	0.01~40	0.05~100	0~0.35
Principal component frequency range (Hz)	0.01~10	0.25~35	0~0.35
Amplitude(V)	-4~4V	-1~3v	0~2.5
Sampling rate	32Hz	128Hz	32Hz

Table 4-14. The list of amplitude frequency characteristics of the five physiological signals.

It can be seen that all of the signals were slow-speed signals, therefore limited emphasis was placed on either the ADC sampling rate or the absolute sampling accuracy, the focus being the differences between the signals. The requirements of the ADC resolution of the system were not high either. However, taking into account the application of intelligent fashion on special occasions, other requirements of the system on the sampling signal were essential:

- Low noise.
- Low power consumption.
- Low requirement of signal relative accuracy (i.e., low INL and DNL).
- A minimum of 3 circuit inputs with MUX switch channel not required to be connected to the external.
- Simultaneous sampling of three physiological signals.

After comprehensive consideration, an AD7927 chip (ANALOG DEVICES, 2003-2008) was selected for the ADC of the system. AD7927 is a 12-bit, 8-channel and successively-approaching ADC which has low power consumption and the highest throughput capacity - up to 200 Kbps, using 2.7 V to 5.25 V single supply. The device contains a low-noise, broad-band sampling hold amplifier which can process input frequency of over 8 MHz. AD7927 has 8 single-ended analog inputs (AIN) with tap channel MIDI and can select a channel conversion sequence through pre-programming. Through the configuration of the control register, the analog input range of the devices can be chosen from 0V to 2V of the reference voltage; either standard binary system or complement of binary system output coding can be adopted for output encoding.

Sampling of the input signal is performed on the trailing edge of CS-chip selection lead pin, and it is here where conversion is initiated simultaneously, i.e., previous sampling results can be retrieved at the same time with the configuration of sampling control for current results. As a consequence, the device would not incur any delay in the production process. This measure can minimize the time interval between two different physiological parameters. Some of the core parameters are listed in Table 4-15.

Power supply	Electric current	Velocity	Resolution	INL	DNL	SINAD
2.7-5.25V	1.5mA	200Kbps	12-bit	0.3LSB	0.4LSB	71dB

Table 4-15. AD7927 core parameters.

Figure 4-19 shows an ADC circuit, of which VIN0-7 is input analog signal, VREF is external reference voltage, ADCLK, MOSI and MISO are bus interface of ADC and SPI of MCU, /CS_7923 is AD7927 gate signal, low level is effective, and VDRIVE supplies power for the logic part.

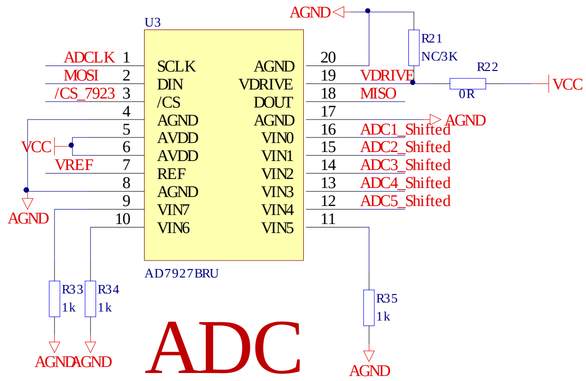


Figure 4-19. ADC circuit diagram.

VREF which is the reference voltage of ADC was selected as 2.5V. The parameters are shown in Table 4-16.

Original precision	Temperature coefficient	Supply current
±2 mV	5 ppm/°C	45 µA

Table 4-16. REF192 core parameters.

Since the input end of ADC does not support negative analog input, voltage adjustment circuit is set at ADC front-step, using the two adjustable resistances of R42 and R48 to adjust positive and negative input signal linearity to 0 - 2.5V.

IV. MCU module

MCU is mainly used to read the sampling value of ADC and send the current sampling value to the upper computer through the serial, and LED lights are driven to show the color values representing the current emotion value after emotion recognition by the upper computer. In the absence of an externally-connected upper computer, the ADC sampling value and clock information can be saved into the externally-connected USB through the USB chip for future research purposes. The singlechip machine (SCM) SST89E516RD of 51 structure with a maximum operating frequency of 40MHz was selected as the MCU. The main features of SCM (codesworks, 2010) are as follows:

- Internal RAM is of 1Kbyte (256Byte + 768Byte) in total.
  - Contains two high-performance SuperFlash memorizers (EEPROM)
  - 8K/16K/32K/64Kbyte primary memory block+ 8Kbyte secondary memory block
- Section size of each block is 128Byte.
- 3 16-bit timer/counter (T0, T1, T2)
- Full duplex enhancement mode serial COM ports (UART)
- 10 interrupt sources, 4 priority levels (PRI)
- Support the second DPTR register
- Standard 12 clocks per instruction cycle, 6 clocks per instruction cycle can be achieved through frequency doubling
- TTL and CMOS electrical level are fully compatible

Figure 4-20 shows the MCU circuit, of which P0 port constitutes the data bus, P2 port provides the address, with the former mainly responsible for serial communication (SPI, IIC, DS1302 bus) and status indicator section.

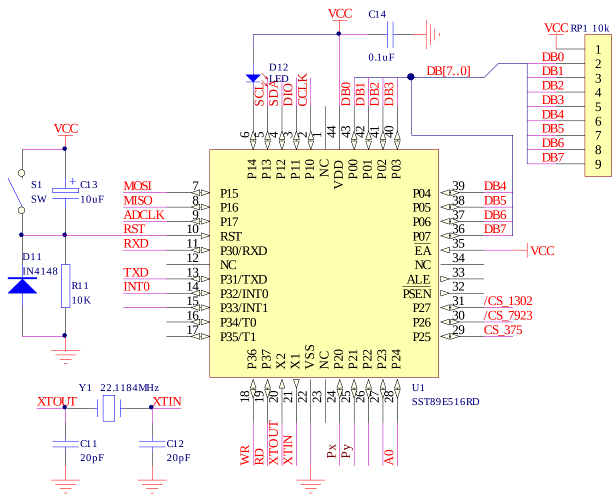


Figure 4-20. MCU circuit diagram

V. IIC (intensifier circuit)

MCU is connected to four LED lamp drivers through IIC bus, and in order to ensure the quality of IIC serial communication, the system especially uses P82B96 (codesworks, 2010) bidirectional bus buffer. P82B96 is a two-way logical interface device that is of bipolarity and with an internal latch. It provides a bridge connection between the standard I2C device and distant bus and can bridge-connect similar buses of different voltage and current levels with the I2C bus. The device can bridge SMBus (350μA) and 3.3V logic devices. A 15V electrical-level and low-impedance cable can extend the communication distance and increase the capability of resisting interference. The device has no special requirements regarding the I2C bus protocol and clock rate. P82B96 can increase the minimum load and new bus load as well as the number of I2C bus devices on I2C bus node, without any adverse effects on local node. The number of couplers and physical restrictions will be greatly reduced as well. The detailed IIC Dual bidirectional bus buffer circuit diagram is shown in Appendix A.2.4.

VI. RTC circuit (clock circuit)

The system is initially equipped with real-time clock circuit to make data traceable. The selected clock chip is DS1302 (codesworks, 2010) which is a high-performance, low-power-consumption real-time clock circuit with RAM and can time year, month, day, Sunday, hour, minute and second, possessing the function of leap year compensation with a working voltage of 2.5V~5.5V. A three-wire port is used to perform synchronous communication with CPU and the burst method can be used to transmit multiple-byte clock signals or RAM data at one time. Inside DS1302 there is a 31×8 RAM register used for temporary data storage. DS1202 is an upgraded product of DS1302 and is compatible with DS1202. It increases dual power supply pins of main power/back power supply and provides the capability of charging thin current to the power supply. The detailed RTC circuit diagram is shown in Appendix A.2.5.

VII. USB (high-capacity) storage circuit

The main purpose of the USB storage circuit is to expand the SCM storage. When the system work is in off-line measurement state, three kinds of physiological signals measured will be stored in the flash memory disk in FAT32 file format through a CH375 (codesworks, 2010) interface chip.

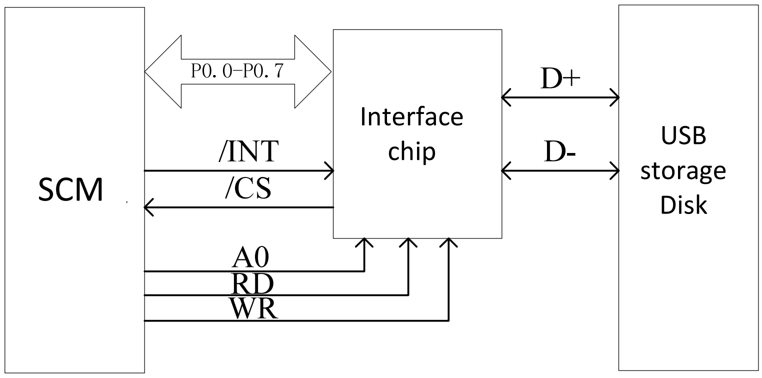


Figure 4-21. The USB interface diagram.

CH375 is a common interface chip of a USB bus. It supports USB-HOST host mode and USB-DEVICE/SLAVE device mode. In a local port, CH375 possesses 8-bit data bus, reading, writing and chip selection (CS) control line and the interrupt output. It can be easily coupled to the system bus of such controllers as SCM (SCM)/DSP/MCU/MPU. In the USB host mode, CH375 also provides serial communication, allowing connection with SCM/DSP/MCU/MPU, etc. through serial input, serial output, and interrupt output. Internal CH375 is also equipped with special communication protocol firmware that handles mass-storage mass memory, while external SCM can directly take section as the basic unit to read and write commonly-used USB storage devices (including USB hard disk/USB flash memory Disk) with features (codesworks, 2010) are as follows:

- Full speed USB-HOST host interface, compatible with USB V2.0. External components only need crystal and capacitance.
- 64 bytes each for host endpoint input and output buffer. Support commonly-used 12Mbps full-speed USB devices.
- Support control transmission, bulk transmission and interrupt transmission of USB devices.
- Automatic detection of USB devices connection and disconnection, provision of equipment connection and disconnection event notice.
- Built-in protocol processor of control transmission to simplify common control transmission.
- Built-in special communication protocol for firmware handle mass storage device,

support USB storage device (including USB hard disk/USB flash memory disk) of bulk-only transport protocol and SCSI, UFI, RBC or equivalent order volume.

- Realization of SCM reading and writing document in USB storage devices through U disk file-level subroutine library.
- Parallel interface consists of 8-bit data bus, 4-wire control: read gate, write gate, chip selection (CS) input and interrupt output.
- Serial interface-SI contains serial input, serial output, interrupt output, support for communication baud rate dynamic adjustment.

The detailed USB circuit diagram is shown in Appendices A.2.5.

VIII. Serial circuit

The serial circuit mainly realizes conversion between TTL electrical level and RS232 electrical level used by the upper computer. The system uses a classical electrical level conversion chip-MAX232. The detailed serial circuit diagram is shown in Appendices A.2.5.

The holistic framework of the circuit design of electronic system is shown in Figure 4-22.

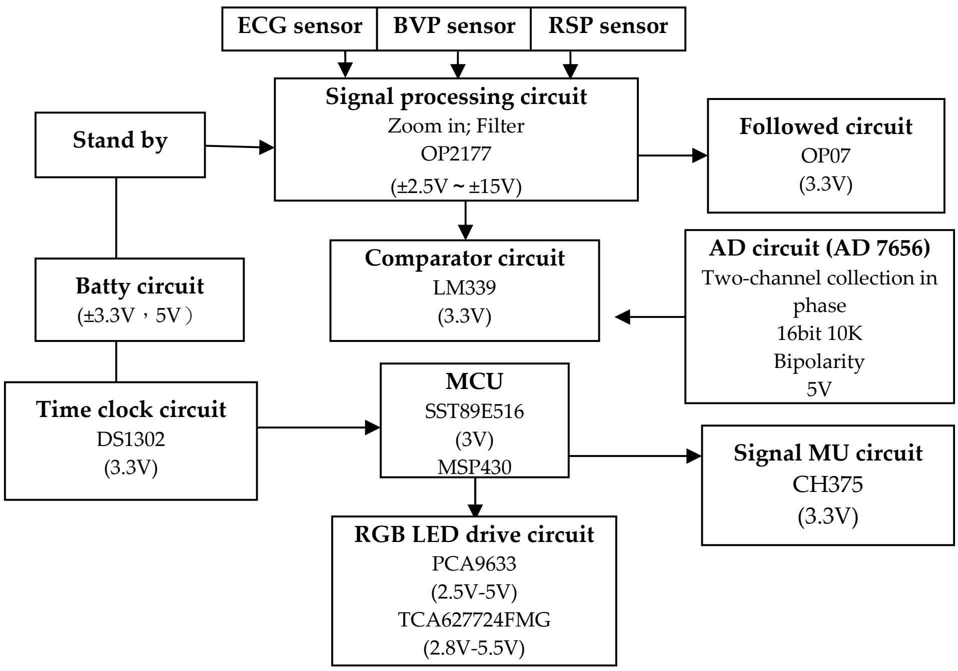


Figure 4-22. The holistic framework of circuit design of electronic system.

Figure 4-23 shows the mainboard of the circuit of the electronic system. MCU, ADC, VREF, DC-DC Converter, Serial circuit chip, USB Controller, USB interface, IIC interface, DC input are distributed on the mainboard.

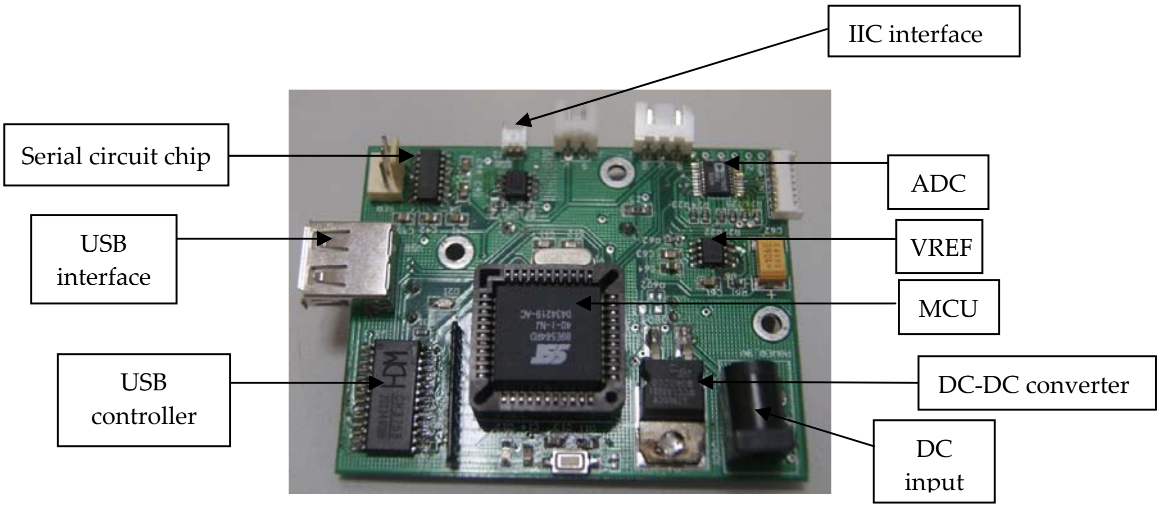


Figure 4-23. The mainboard of the circuit of the electronic system.

4.3.3.2 Software design

As discussed in the earlier section, the system hardware supports two operating modes. This section introduces the specific software flow chart of these two modes.

A. on-line detection mode software flow

When the system is in the on-line detection mode when the measurement system is connected to the upper computer through the serial, the system will take the high 8-bit physiological signals measured in every 128Hz and send them to the upper computer in real time through the serial. The system will stop sending data after collecting for two minutes (when the counter has reached 15,360). After the upper computer has detected the based on the real time data, the details of the identified emotional state will be sent back to the lower computer, and corresponding LED lights will then be activated to display the current emotion state. After the LED is displayed, the system continues to enter standby mode, waiting for the upper computer to issue further instructions about acquisition again. In the on-line detection mode, the baud rate of the lower computer is set at 115200 in order to transmit the five kinds of physiological signals efficiently to the upper computer. Considering the fact that human noise is considerable, the signals sent to the upper computer only take the highest 8 bits of the signals, which saves communication costs on the one hand, and simplifies the data processing, in addition to which the levels of accuracy are generally higher, and high-frequency noise can be filtered out. The entire flow chart is as Figure 4-24.

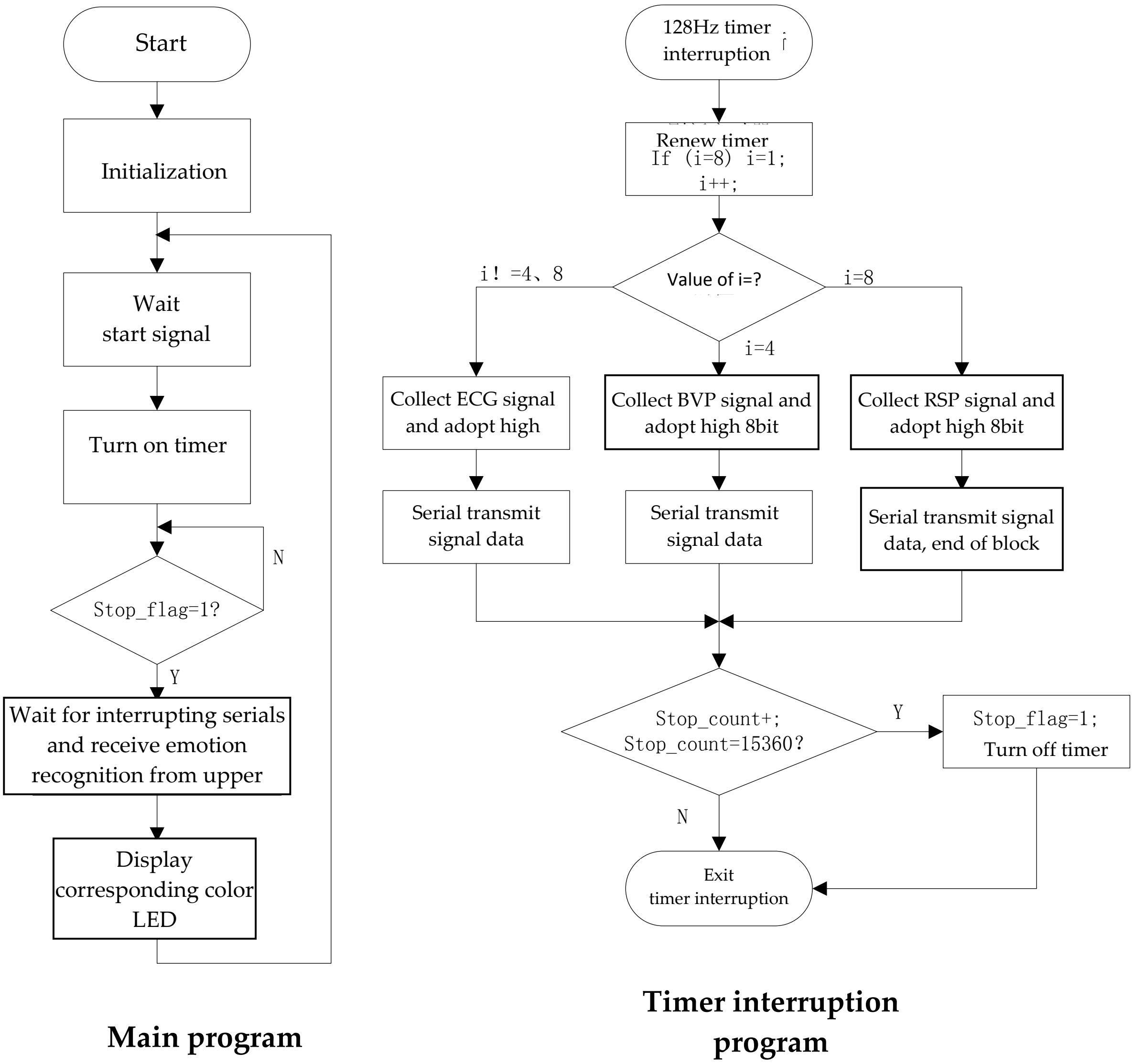


Figure 4-24. The software flow chart of the online detection mode.

B. Offline measurement mode software flow

In offline measurement mode, the system is not connected to the upper computer, yet SCM does not have sufficient ROM to store long-time physiological data. Therefore, the system was externally expanded by means of the CH375-USB interface circuit to connect a USB storage disk outside and expand the storage capacity. CH375 requires at least a 512Byte read-write cache, however, SST89E516 SCM has RAM of less than 1K while time for reading and writing an external section through CH375 requires more than 200ms. Therefore, it is very likely that the system is full in 512Byte read-write cache, and when the U disk flash memory executes reading-writing tasks, the remaining space in SCM is not enough to store the new physiological signal data, resulting in data loss. After comprehensive consideration, a 64K flash within the SCM was used as cache. All measured data will first be stored in the internal flash memory disk, and they will be sent to the external flash memory disk two minutes after collection, i.e., when Block0 address reaches 0x88B0. From acquisition completion to the start of the next acquisition, the system will reserve two minutes to allow data to be fully transferred to the flash memory disk.

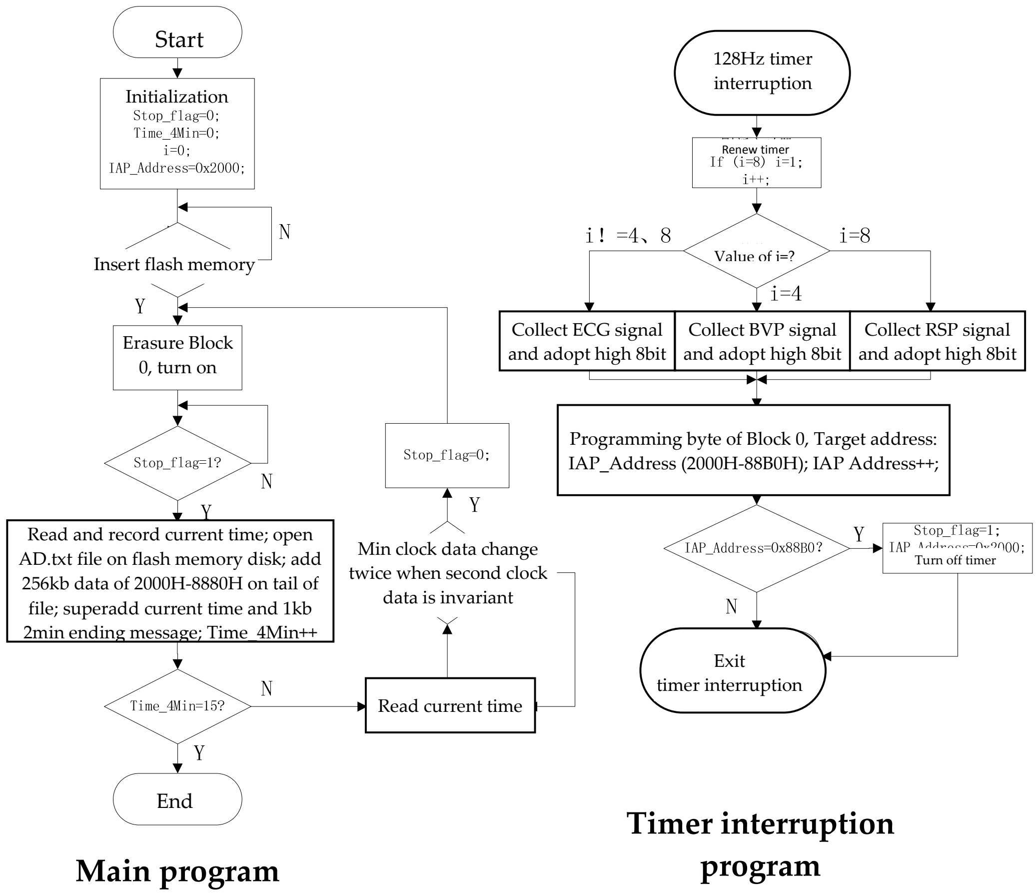


Figure 4-25. The software flow chart of the offline detection mode.

4.3.3.3 LED program design

IF the emotional changes of the wearers are mainly signaled through changes of LED lights embedded in their clothes, then the indication effects of LED light are particularly important. By comparison, the system selects a LED driver - PCA9633 (NXP, 2008) to achieve more exquisite color performance. PCA9633 is a 4-bit LED drive through IIC bus-mastering. This drive specifically optimizes mixed application of red/green/blue/amber (RGBA) colors. In independent luminance adjustment mode, each LED output has an individual PWM controller that is of 8-bit resolution (256 levels) and fixed frequency. This controller runs on the frequency of 97 kHz and its duty cycle is adjustable from 0% to 99.6% to set LED at a specific luminance value. In addition, the drive has a group PWM controller that is of 8-bit resolution (256 levels). Operating frequency of the controller can be fixed at 190Hz and can also be adjusted from 24Hz at 10.73 seconds intervals (about 0.093Hz), and its duty cycle is adjustable from 0% to 99.6% to standardize all LED dim or flash values.

The output state of each LED can be set off, on (without PWM control), or be determined by the value of its independent PWM controller or the value of the independent PWM controller and group PWM controller. LED output drive can be programmed as the open-drain mode that is of 25mA current absorption capacity (sink current) at 5V voltage or the push-pull mode that can absorb 25mA sink current and provide 10mA pull current at 5V voltage. PCA9635 operating voltage ranges from 2.3V to 5.5V and its output voltage can tolerate 5.5V LED can be directly connected to the LED output pin (up to 25mA, 5.5V), and large-current or high-voltage LED can be driven by PCA9633 and an external drive as well as a small number of discrete components. The IIC-bus address of software programmable LED group and three sub calls allows all or specific PCA9633 device groups to respond to the same IIC bus address, e.g., all the red LED lights are allowed to be simultaneously on or off or achieve horse race lamp effect so as to reduce IIC bus commands.

PCA9633 has 10-pin package and 16-pin package, and for the system a 10-pin package was selected which provides only two address lines, thus the system can only be installed with 4

LED light panels at most. However, the control panel is also compatible with 16-pin packaged PCA9633, and the board has a jumper network which can be configured for selection of both a 10-pin and a 16-pin package, and up to 7-bit address wires. By configuring different addresses to each LED light control panel, each board can be identified by the system. The control board of the LED display in detail is shown in Appendix A.2.6.

LED selection and configuration involved flexible LED and re-order LED light strip of appropriate specifications according to the setting needs of the system, with each RGB LED light being able to independently light. Each LED light control panel can be connected with a LED light strip, and all LED lights on the connected light strip are of the same performance results. These light strips can be cut in any way and divided into independent single lights to be attached to different parts of clothes. Lights are connected by a wire, and all single lights connected together by a wire are of the same color expression capability. Figure 4-26 is the full size drawing of initial LED light strip. And the re-designed LED light strip specifically for this research is shown in Figure 4-27.

Figure 4-26. Initial LED light strip.

Figure 4-27. Re-designed LED light strip.

RGB LED can produce different LED light color and luminance presentation effects by means of a mixed color setting program. The following are the effects and corresponding sets data for several RGB color combinations.

Colors	LED lights	RGB data
White		R:255 G:255 B:255
Yellow		R: 246 G: 255 B: 0

Pink		R: 255 G:25 B: 198
Purple		R: 233 G: 0 B: 254
Red		R: 254 G: 0 B: 0
Blue		R: 0 G:6 B: 254
Green		R: 0 G: 192 B: 50

Table 4-17. The effects and corresponding set data of several RGB colors

4.4 Explorations and Experimentations of Materials and Design Methods of LED Display

In this research, the IF design aimed to show different visual effects and relative interactive experiences through changes of LED from within clothes. Therefore, in addition to the above interior designs related to the system, the IF external appearance was one of the key points of the experimental work. This section reports the application of different kinds of materials in LED light visual display and the series of classifications of comparative experiments conducted by which the most suitable material for creation of IF design on the basis of LED features and display effects was identified. Experiments were conducted on a variety of LED design and expression methods by which the method that was ultimately applied into creations of IF design was determined.

4.4.1 Tests of material and LED applications

Materials were classified according to the categories of texture, thickness and color for experiments varying the LED display effects. Test items included luminance, transmittance range, color reversion, and variation.

4.4.1.1 Texture

Materials having eight distinctive textures were selected for the experiment, i.e., silk chiffon, silk satin, cotton, polyester, leather, wool, plastic and pectin, all of which were of similar color. Tests for the 4 items specified above, using specific RGB mix-colored LED, were performed on the 8 groups of materials characterized by their different textures.

Group 1: RGB LED: white (R: 255, G: 255, B: 255)

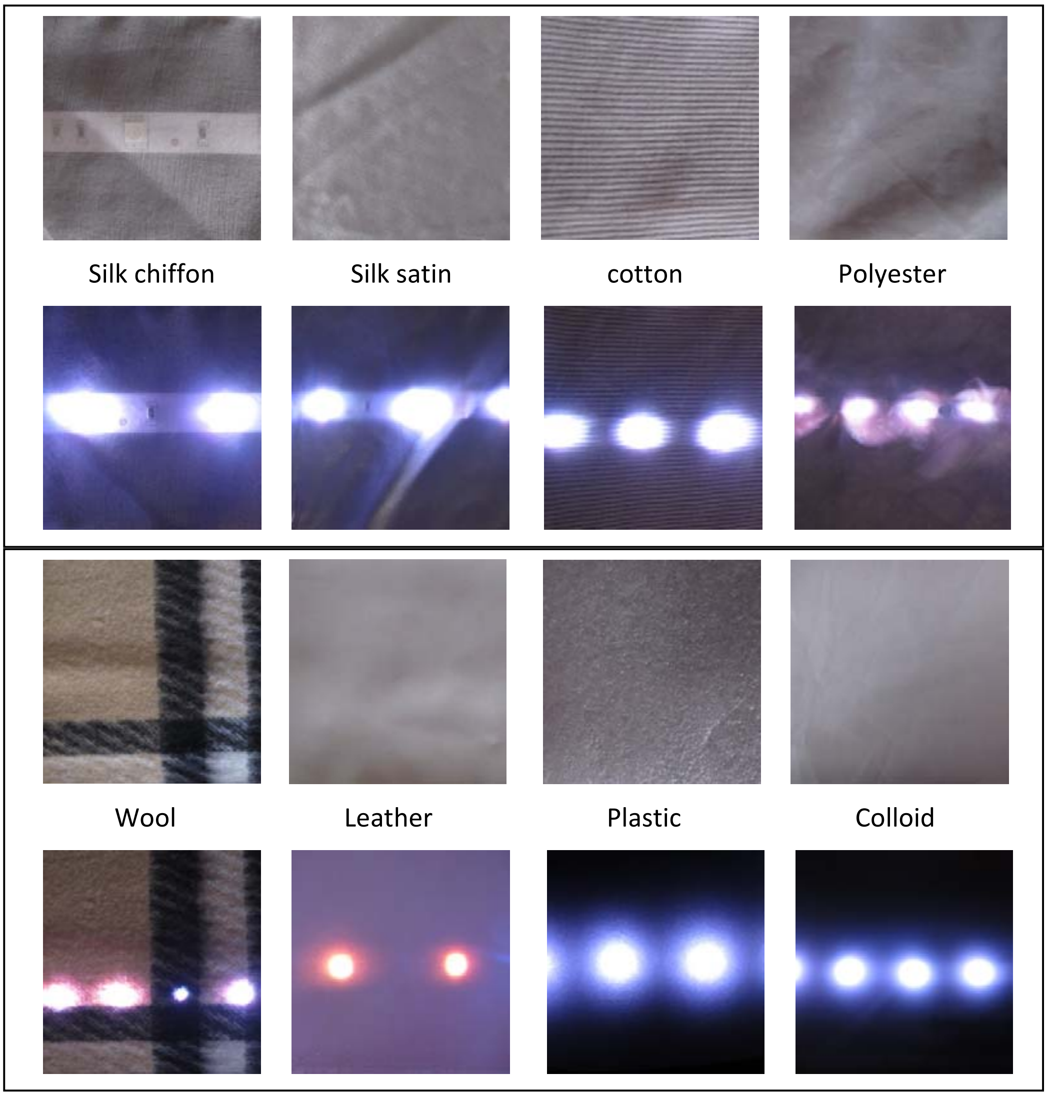


Figure 4-28. Group 1: RGB LED white with eight types of textures.

RGB LED was tuned to white light and was placed on the bottom of each of the test samples. Figure 4-28 shows that the luminance of the LED placed under silk chiffon and sill satin was relatively high; while luminance of LED placed under polyester was the lowest. In the transmittance range, LED placed under silk chiffon was of the largest light scattered area but the change of level was not exquisite; whereas LED placed under leather was of the smallest light scattered area. LED placed under cotton was of the highest color reversion; whereas LED placed under wool and leather was of relatively low color reversion. After comprehensive assessment of the variations of light, it was found that LED placed under wool and leather demonstrated comparatively more obvious changes.

The test result of group 1 is shown in the below Table 4-18:

Textures	Luminance	Transmittance range	Color reversion	Variation
Silk chiffon	+++++	+++++	++++-	+-
Silk stain	+++++	++++-	++++-	+-
Cotton	++++	+++	+++++	++
Polyester	+-	++-	+++	++++-
Wool	++	++	++-	+++++
Leather	++	+	+	+++++
Plastic	+++	+++	++++	+++
Colloid	+++	++-	++++	+++

N.B. The number of '+'indicates the extent. The more the '+', the stronger the degree. '-' stands for half of '+'.

Table 4-18. The test result of group 1

Group 2: RGB LED: red (R: 254, G: 0, B: 0)

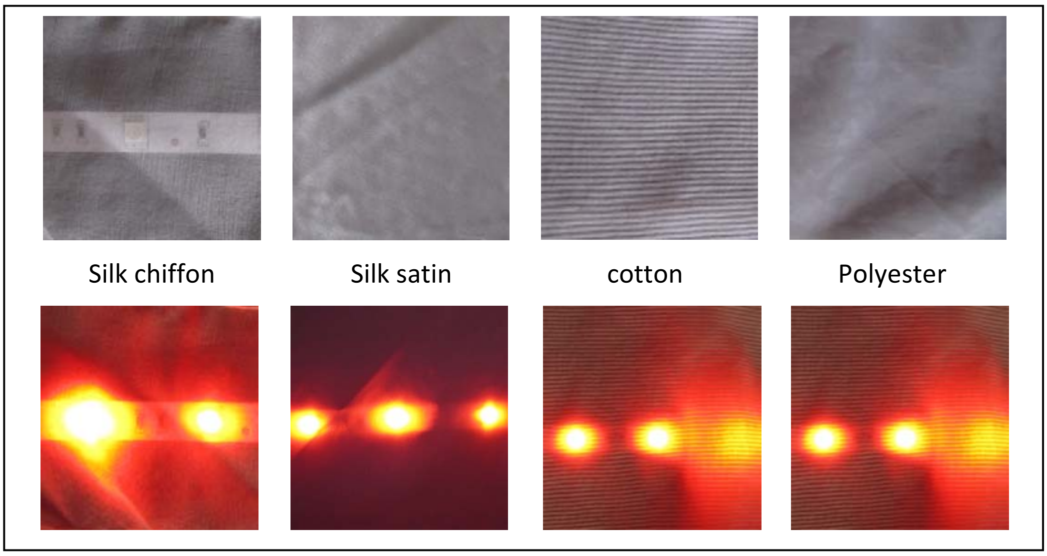


Figure 4-29a. Group 2: RGB LED red with eight types of textures.

Light penetrability of RGB LED placed under red color was slightly higher than that for white.. Figure 4-29a/b shows that red LED and white LED performed similarly in the case of all of the materials. The luminance differed in that red color LED placed under leather was of relatively low luminance compared with when it was placed under polyester. Color reversion of this group was higher compared with the first group, resulting in a low degree of variation.

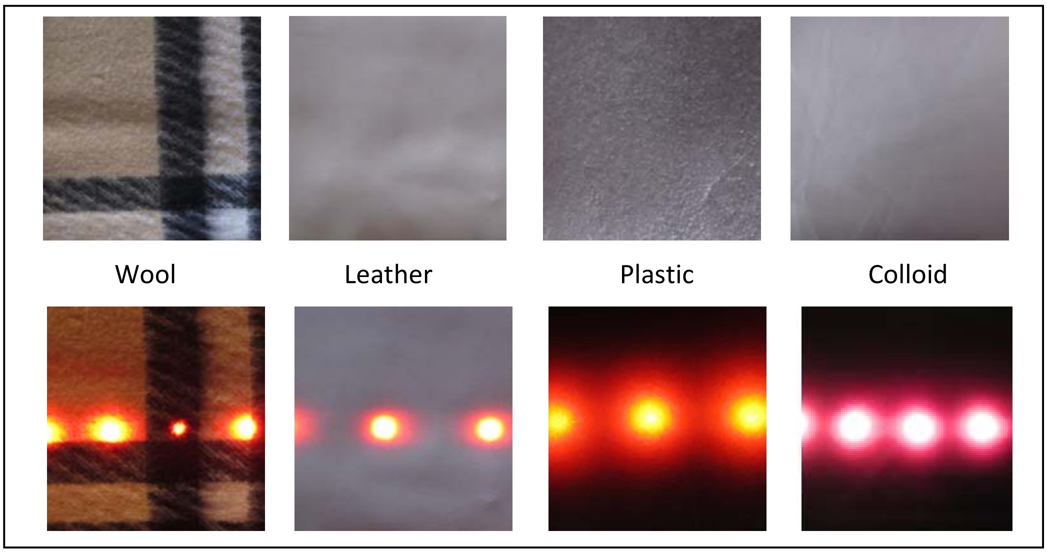


Figure 4-29b. Group 2: RGB LED red with eight types of textures.

The test result of group 2 is shown in the below Table 4-19:

Textures	Luminance	Transmittance range	Color reversion	Variation
Silk chiffon	+++++	+++++	+++++	-
Silk stain	+++++	++++-	+++++	+
Cotton	++++	+++	+++++	+-
Polyester	++	+++	++++	++-
Wool	++	+-	+++-	+++-
Leather	+-	+	+++	++++
Plastic	+++	+++	+++	+++-
Colloid	+++	++-	++	++-

N.B. The number of '+'indicates the extent. The more the '+', the stronger the degree. '-' stands for half of '+'.

Table 4-19. The test result of group 2.

Group 3: RGB LED: blue (R: 0, G: 6, B: 254)

In this group, the blue RGB LED light was of weaker penetrability than that of the previous two groups. From the figure it can be seen that blue LED placed under leather was within the weakest luminance and transmittance range, and that the transmittance range in particular did not even have radiation glow. In color reversion, the reduction degree was the best when placed under plastic.

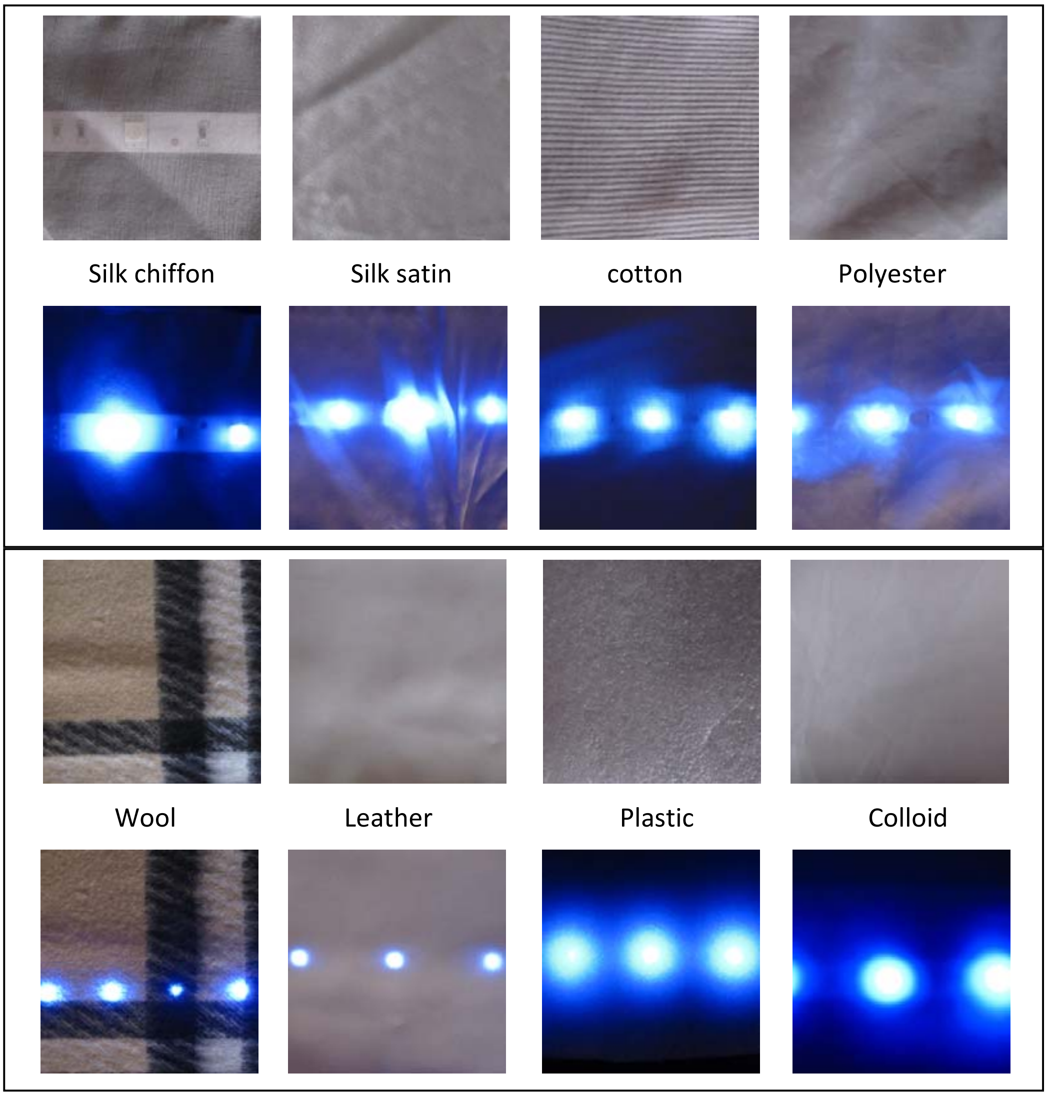


Figure 4-30. Group 3: RGB LED blue with eight types of textures.

The test result of group 3 is shown in the below Table 4-20:

Textures	Luminance	Transmittance range	Color reversion	Variation
Silk chiffon	+++++	+++++	++++-	-
Silk stain	++++	+++	+++-	+++
Cotton	+++	+++	+++-	+++
Polyester	++	++-	+++	+++-
Wool	++	+	+++-	++++
Leather	+-	-	++-	++++-
Plastic	+++-	+++-	++++-	++
Colloid	++++	++++	+++++	+-

N.B. The number of '+'indicates the extent. The more the '+', the stronger the degree. '-' stands for half of '+'.

Table 4-20. The test result of group 3.

Group 4: RGB LED: green (R: 0, G: 192, B: 50)

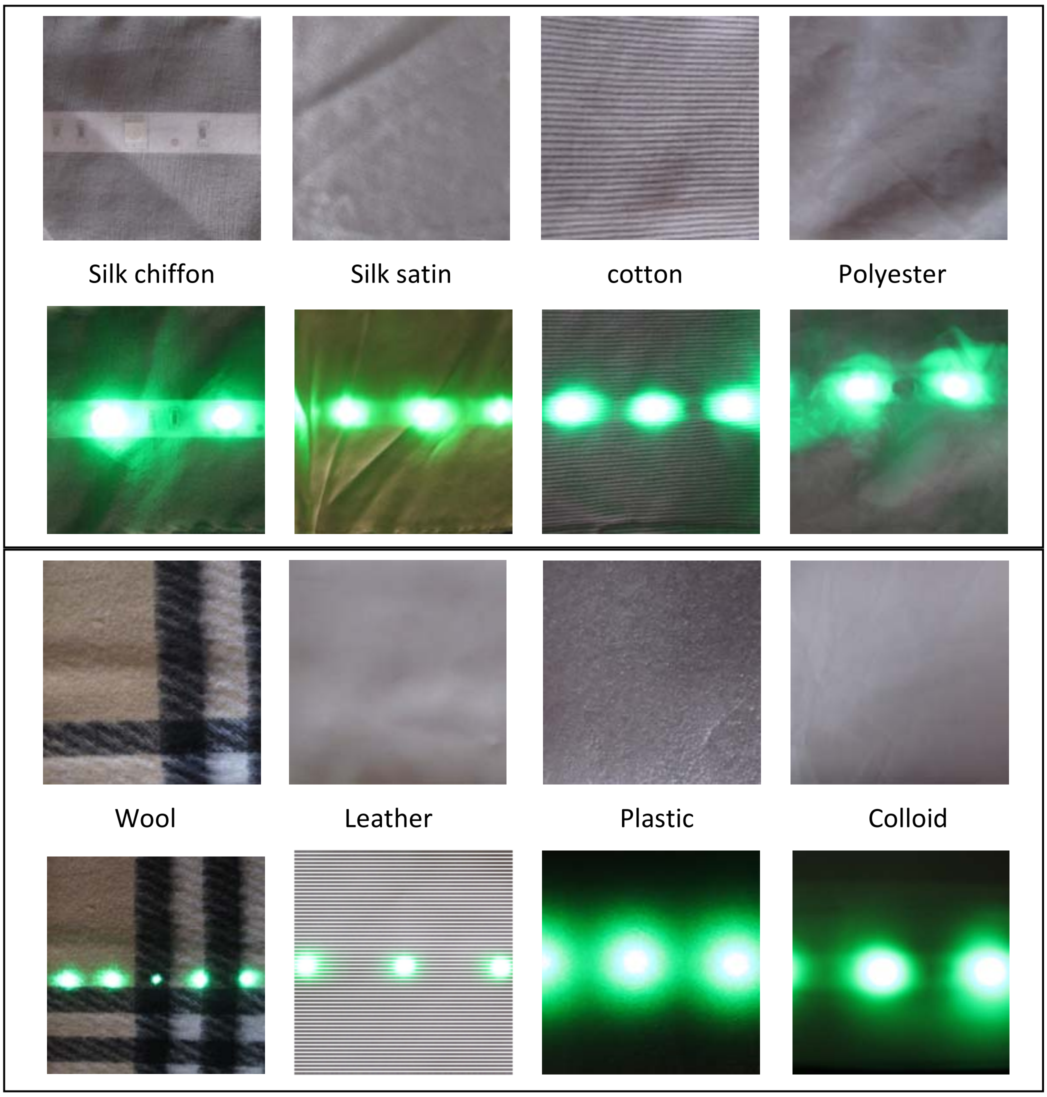


Figure 4-31. Group 4: RGB LED green with eight types of textures.

In the forth group, RGB LED was set to green (R: 0, G: 192, B: 50). The penetrability of the green light was slightly better than that of the blue. The luminance of the 8 textures was relatively even; in color reversion, there was no big difference either, and the color difference was negligible. Greater difference could be found in the transmittance range, which indicated that texture has a significant impact on LED performance.

The test result of group 4 is as shown in the below Table 4.21:

Textures	Luminance	Transmittance range	Color reversion	Variation
Silk chiffon	+++++	+++++	+++++	-
Silk stain	+++++	++++	++-	+++
Cotton	++++-	++-	++++	+++
Polyester	++++	+++	++++	++-
Wool	++++	+-	+++-	++++
Leather	+++	+	+++-	++++
Plastic	++++	+++-	++++	++
Colloid	++++-	+++-	+++-	+-

N.B. The number of '+'indicates the extent. The more the '+', the stronger the degree. '-' stands for half of '+'.

Table 4-21. The test result of group 4.

4.4.1.2 Thickness

Materials of different thickness were selected to test the performance effects of the LED. Similarly, each group used a RGB mixed-color LED for the test. To avoid the influence of other factors arising from the textures, a white textured silk was selected in the tests below and the thickness was varied by means of the number of layers, the selected LED color being white. Figure 4-32 shows the performance effects of white LED for the same texture but different thicknesses. The thickness was equal to the distance between the LED light source and the contacted covering. From ultra-thin to ultra-thick, this distance increased with the increments of thickness with small incremental coefficients but obvious contrast effects. In the ultra-thin state, luminance of the light of the LED was dazzling, the light scattered area

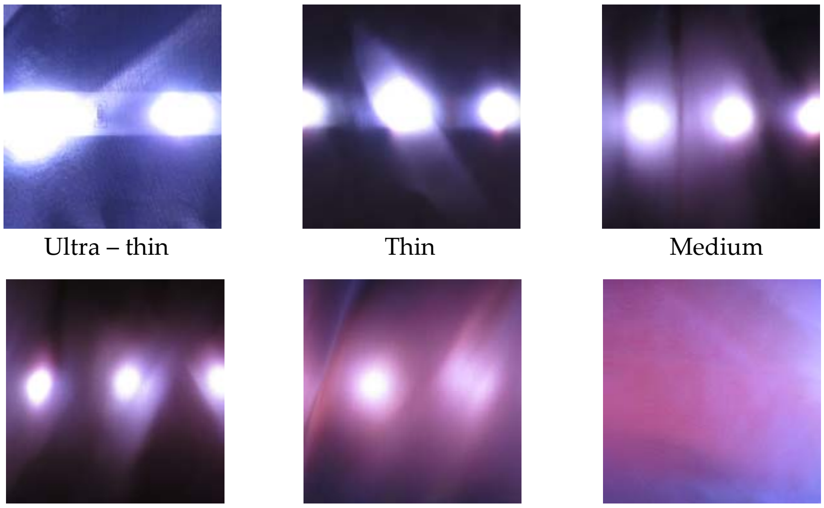


Figure 4-32. White LED with different thickness.

was large, light points were clear, the glow area was large and bright, but level changes were small. When the thickness was increased, the luminance factor significantly decreased, the visual effect was soft, light dots were fuzzy but still visible, the area of the glow was relatively large and scattered in levels in pink. When the material was exceptionally thick, the light spot disappeared; luminance coefficient was the weakest, the visual effect was rather soft, and the color of the light changed from the original white to light pink.

The test results for the white LED using material of the same texture and of different thicknesses is shown in Table 4-22.

Thickness	luminance	Transmittance range	color reversion	variation
Ultra-thin	+++++	+++++	+++++	-
thin	++++	++	++++-	+-
medium	+++	+++	+++-	++
Slightly thick	++	+++	+++	+++
thick	+-	+++-	+-	++++
Ultra-thick	+	+++-	-	+++++

N.B. The number of '+'indicates the extent. The more the '+', the stronger the degree. '-' stands for half of '+'.

Table 4-22. Test result of white LED with different thicknesses.

4.4.1.3 Color

Different typical colors of the same texture were selected to test RGB LED performance effects when colors were mixed. To highlight typicality, RGB and white were selected for the test. The material made from cotton was of relatively uniform texture, thus white, red, green, blue and black cotton samples were selected to conduct the comparison tests.

Sample1: White cotton

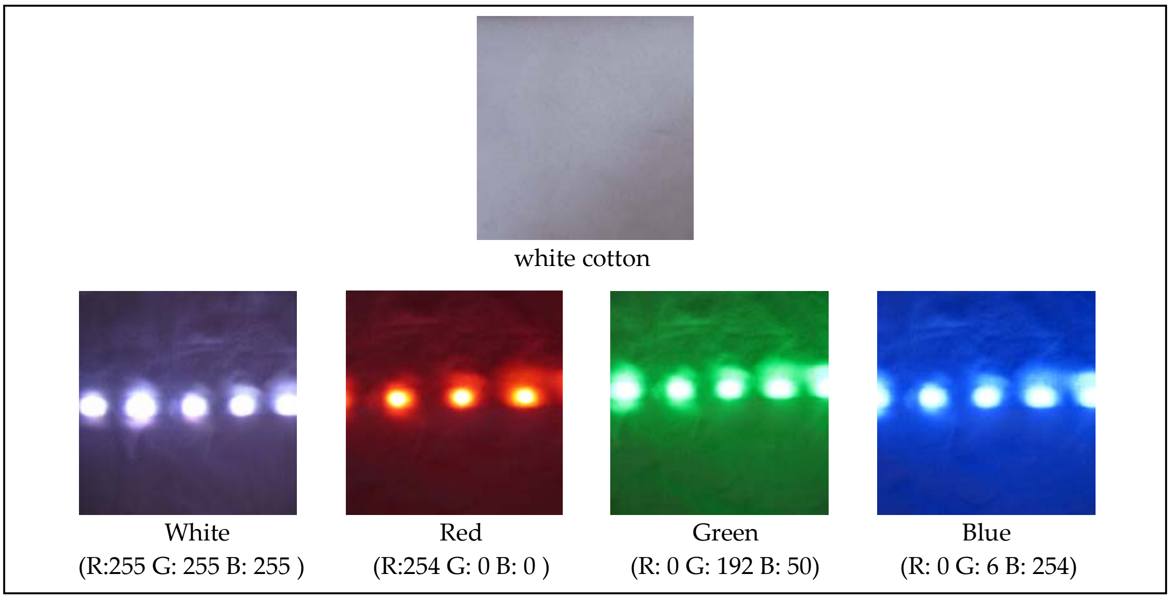


Figure 4-33. Sample 1: four colors RGB LED with white cotton.

Sample 2: Blue cotton

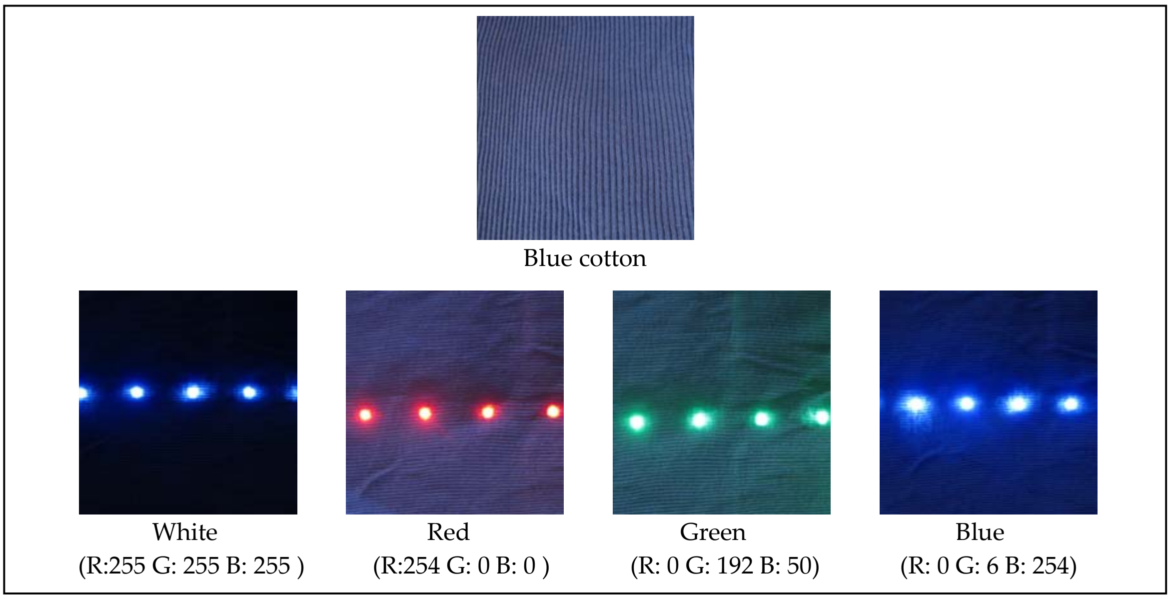


Figure 4-34. Sample 2: four colors RGB LED with blue cotton.

Sample 3: Red cotton

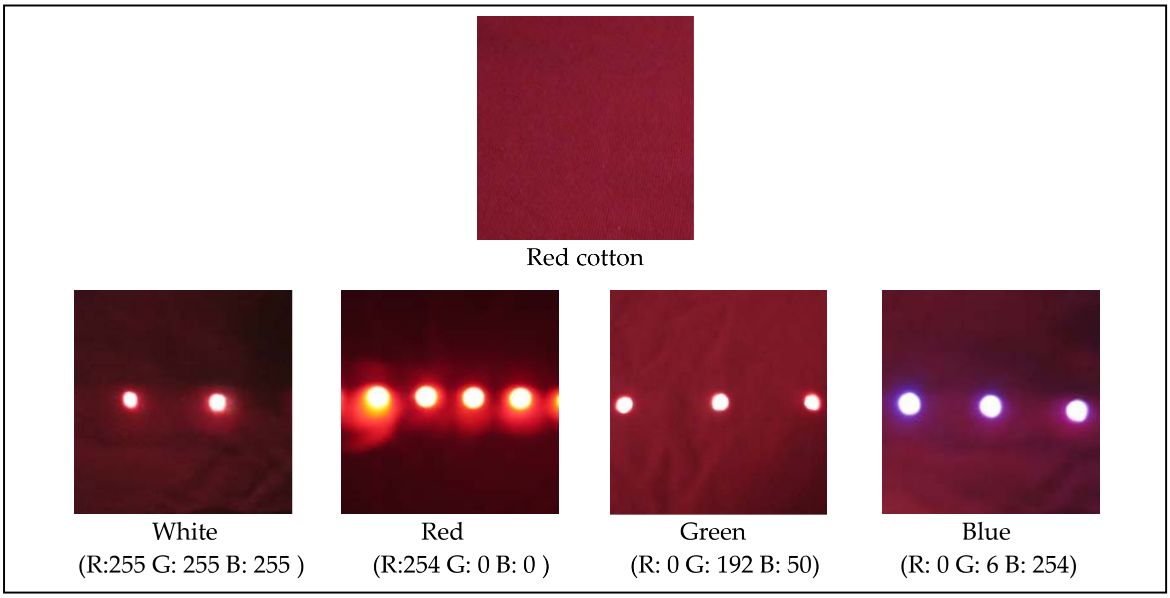


Figure 4-35. Sample 3: four colors RGB LED with red cotton.

Sample 4: Black cotton

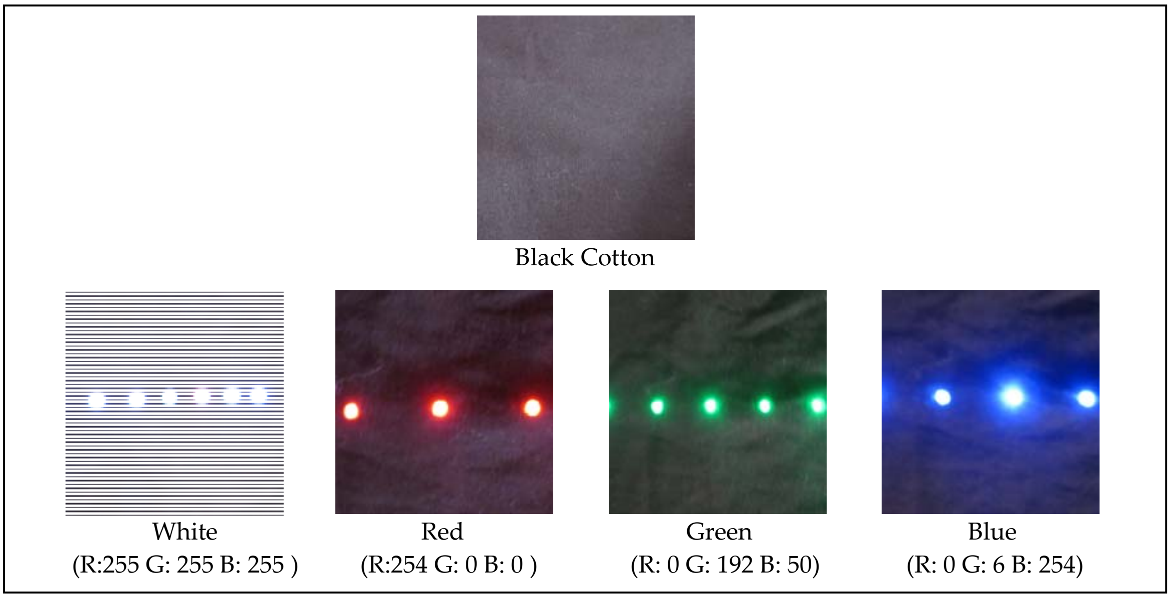
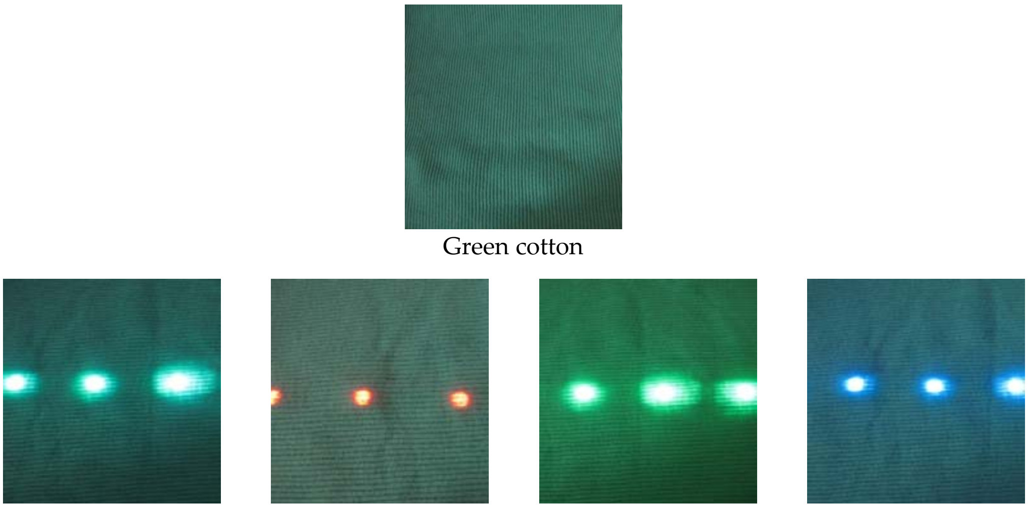


Figure 4-36. Sample 4: four colors RGB LED with black cotton.

Sample 5: Green cotton



Green cotton

White (R:255 G: 255 B: 255) | Red (R:254 G: 0 B: 0) | Green (R: 0 G: 192 B: 50) | Blue (R: 0 G: 6 B: 254)

Figure 4-37. Sample 5: four colors RGB LED with green cotton.

The results of the comparison tests of LED base colors in cotton textiles of different colors were that sample 1 (white) was most obviously impacted by the LED light color. and the original sample color could not be identified visually. Of the four LED base colors, except for the white which had a certain color cast, the other 3 base colors were better maintained. In the case of sample 2 (blue), since the sample itself was blue, the light color performance of the samples was similar under white and blue LED lights, although the light color under the influence of the blue LED was slightly brighter, making the sample bluer. Sample 3 (red) was not greatly influenced by the LED light color, contrarily, the color *per se* had greater influence on LED light color performance and resulted in a complementary color effect. For example, blue LED mixed with red produced purple color light. Sample 4 (black), as the chart shows, had a greater influence on LED light color, which was only second to that of sample 1 (white). The light dispersion of green LED and blue LED was the most obvious, making the black sample looked somewhat dark green or dark blue.

The test result of four colors RGB LED with same texture in different colors:

Colors	LED	luminance	Transmittance range	color reversion	variation
White	W	+++++	+++++	+++	+
	R	++++	+++++	++++	-
	G	+++++	+++++	++++	-
	B	+++++	+++++	++++	-
Blue	W	++++	++	-	++++-
	R	+++-	+	+++	+++-
	G	++++	++	+++	+++-
	B	++++	++	+++++	+
Red	W	+++	+-	+	++++-
	R	++++	++-	+++++	+
	G	++	+	-	+++++
	B	++++	++	+	++++-
Black	W	+++	+++-	+++-	+-
	R	+++	++++	++++	+
	G	+++	++++	++++	+
	B	+++	++++	++++	+
Green	W	++++	+++	+-	+++-
	R	+++	+	+++	++-
	G	++++	+++	+++++	+
	B	+++	++-	++-	+++

N.B. The number of '+'indicates the extent. The more the '+', the stronger the degree. '-' stands for half of '+'.

Table 4.23. Test result of four colors RGB LED with same texture in different colors

4.4.2 Experiments of design methods of LED display

Generally, LED display depends very much on circuit design, and under normal circumstances, it simply follows that of the circuit design. In order to achieve a richer, livelier LED display for the creations in the experiments, certain non-standard design methods of LED display were tested for various effects.

4.4.2.1 Weaving

This method was inspired by the conventional weaving technique (Hann and Thomas, 2005). The merit of the LED used in this study was that it fulfilled the dual design requirements of IF of being light and thin. Although it is flexible, the LED can only bend in one direction. Yet, the LED could achieve a degree of flexibility similar to that of clothing fabric through various weaving methods, which made them more suitable for different designs of IF. By comparing different methods in conventional weaving techniques, four weaving methods which were more suitable for weaving LED were selected. The four methods can be broadly divided into either weaving in LED stripes such as methods 1 and 2 or weaving with individual LED units connected by conductive wires or supporting materials such as methods 3 and 4. The practical details of the four methods are discussed in the following sections.

- Method 1: LED stripes woven in plain weave

LED stripes were divided into nine stripes of equal length, they were then woven using a plain weave (Figure 4-38-a) (Hann and Thomas, 2005) structure into a square of 10 cm^2. This method can create an area based on woven dots and lines and is suitable for large area of LED display. The figure shows the sample exhibits slight curves which make it suitable to be applied both on flat or curved surfaces.

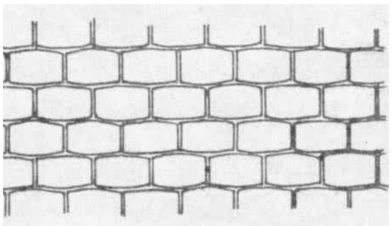


Figure 4-38a. Referenced plain weave.

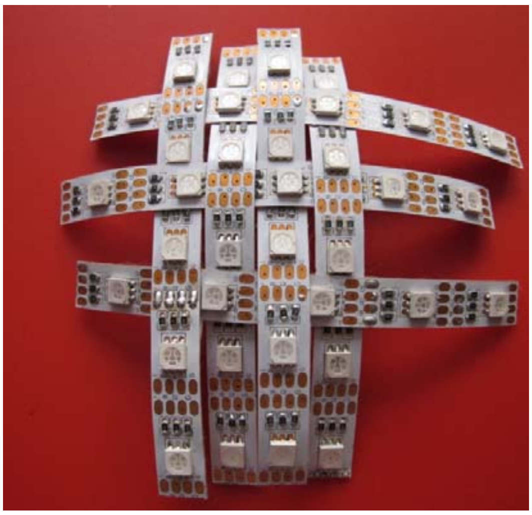


Figure 4-38b. Sample of LED stripes woven in plain weave.

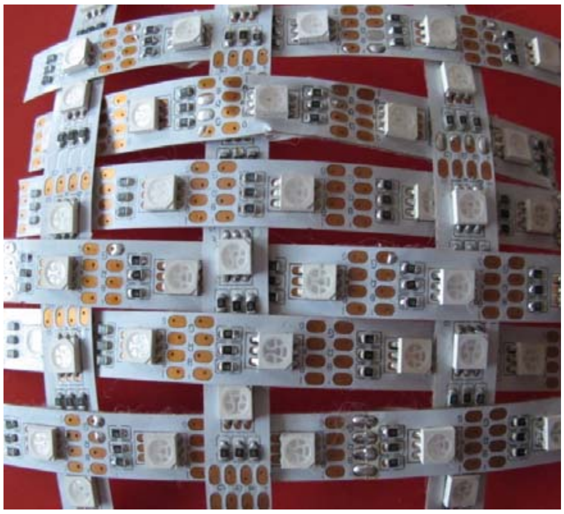


Figure 4-38c. Sample of LED stripes woven in plain weave.

➢ Method 2: LED stripes woven with fabric stripes

Although LED is quite flexible, it does have its limitations in terms of degree and direction of flexibility. In this sample, an attempt was made to weave LED stripes with fabric stripes with the aim to achieve an overall softer sample due to the superior flexibility of the fabric stripes. The materials of LED and fabric stripes *per se* can be used as a kind of clothing fabric too. As is seen in the figures below, the samples woven in LED and fabric stripes is of a superior flexibility which is suitable to be used on human bodily curves.

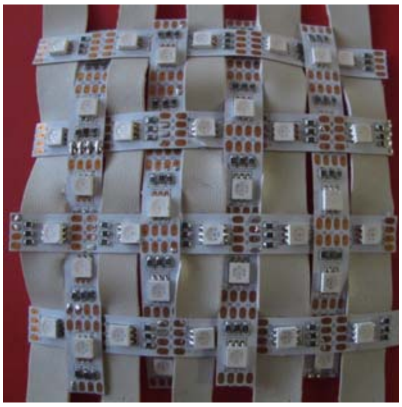


Figure 4-39a. sample 1 - LED stripes woven with fabric stripes.

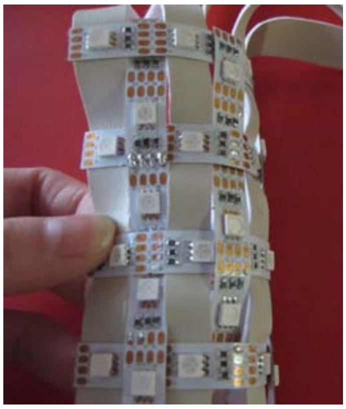


Figure 4-39b. Sample 1 - LED stripes woven with fabric stripes

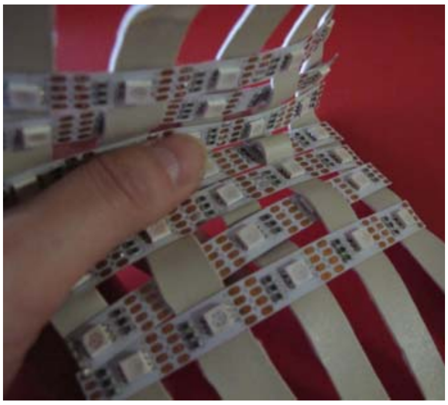


Figure 4-40a. Sample 2 - LED stripes woven with fabric stripes.

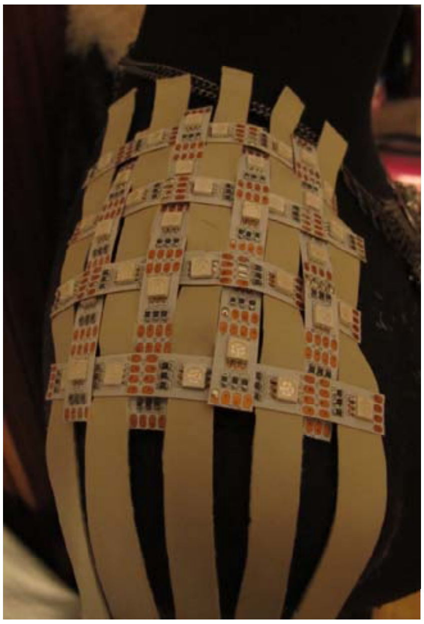


Figure 4-39c. Sample 1 – LED stripes woven with fabric stipes.

Figure 4-40b. Sample 2 - LED stripes woven with fabric stripes
with fabric stripes.

- Method 3: LED single braiding

Various forms of displays could be achieved by cutting up LED stripes into individual LED units connected by conductive wires and textile supporting materials. The sample (Figure 4-41) shows individual LEDs braided with textile supporting materials which can be bent along curves and is ideal for trimming along necklines or cuffs.

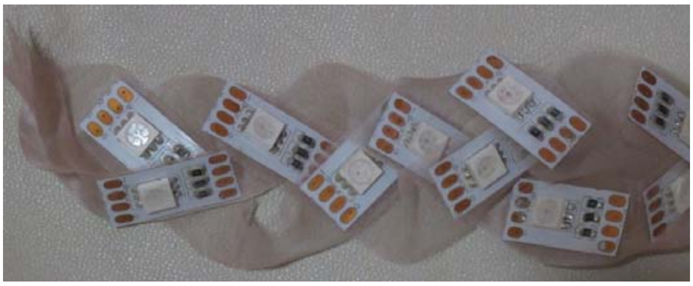


Figure 4-41. Sample of LED single braiding.

- Method 4: Individually connected LED woven in crisscross fashion

Simple symbolic patterns can be produced by weaving individually connected LED in a crisscross fashion.

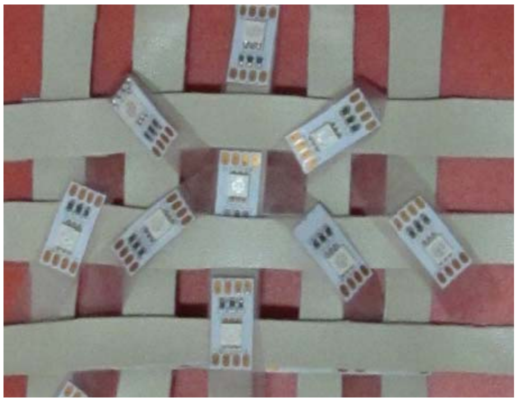


Figure 4-42. Sample of individually connected LED woven in crisscross fashion.

4.2.2 Dot matrix arrangement

Dot matrix arrangement is one kind of display arrangement in the production of an LED screen. The production of the dot matrix arrangement in the screen is relatively complicated due to its high display requirement (Jack, 2005). The LED module is thus thicker and heavier. The dot matrix arrangement used in this experiment was but a reference from the display method of this technique for a relatively simple visual effect.

- Method 1: Symmetrical dot matrix arrangement

The sample 1 in detail is as shown in Figure 4-43a, and the sample 2 in detail is as shown in Figure 4-43b.

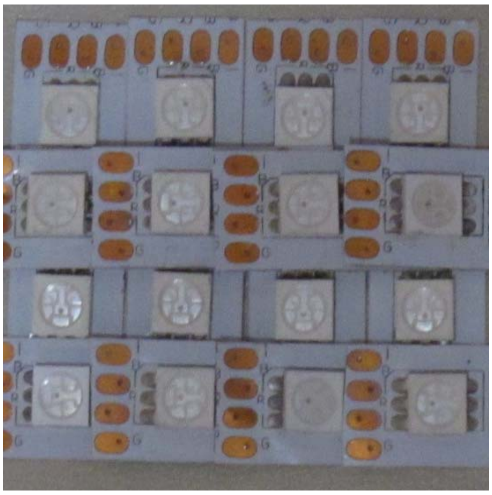


Figure 4-43a. Sample 1 - symmetrical dot matrix arrangement.

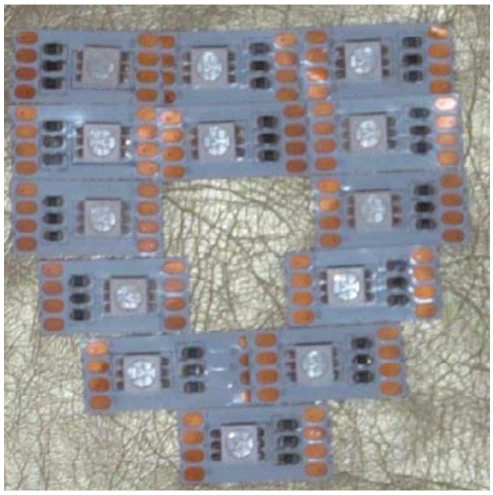


Figure 4-43b. sample 2 - symmetrical dot matrix arrangement.

- Method 2: Asymmetrical dot matrix arrangement

The sample in detail is as shown in Figure 4-44.

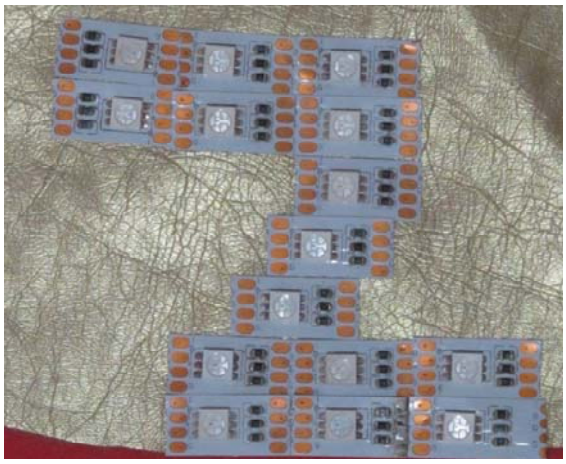


Figure 4-44. Sample of asymmetrical dot matrix arrangement

4.4.2.3 Superposition

Theoretically speaking, desirable colors of LED light can be obtained by combining the software sequence of the LED module with the RGB primary colors. In practice, certain constraints were found in these experiments in the color display when the LED materials selected for the experiments were combined with RGB colors. For instance, certain grey color shades were difficult to mix and display and the color transition was not smooth enough. Thus, superposition could make the LED display finer and richer.

- Method 1: Monochromatic superposition

The detailed sample is as shown in Figure 4-45a and Figure 4-45b.

Figure 4-45a. Sample of monochromatic effect before superposition.

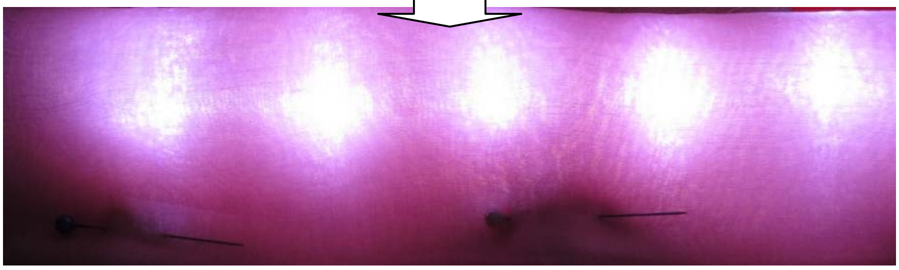


Figure 4-45b. Sample of monochromatic effect after superposition.

- Method 2: Polychromatic superposition

Figure 4-46a and Figure 4-46c showed the polychromatic effect before superposition. Figure 4-46b and Figure 4.46d showed the polychromatic effect after superposition.

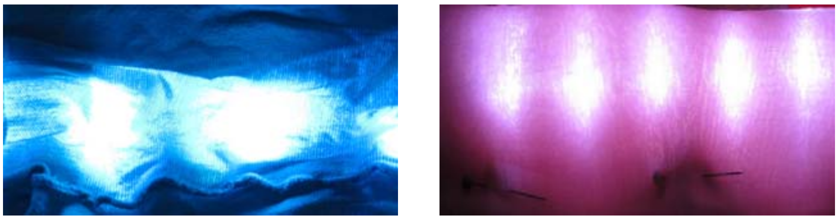


Figure 4-46a. Samples of polychromatic effect before superposition.

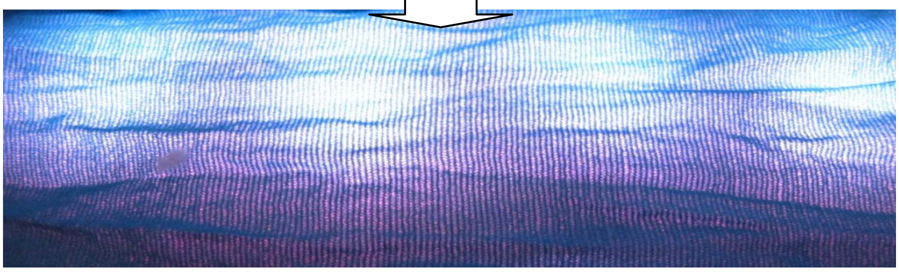


Figure 4-46b. Sample 1 of polychromatic effect after superposition

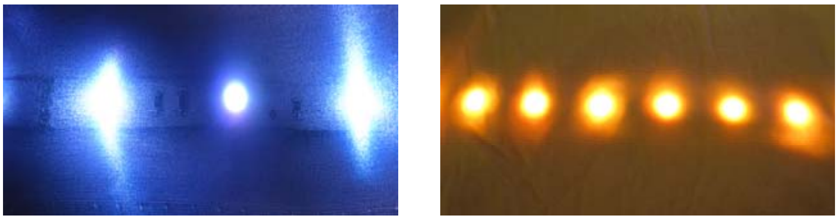


Figure 4-46c. Samples of polychromatic effect before superposition.

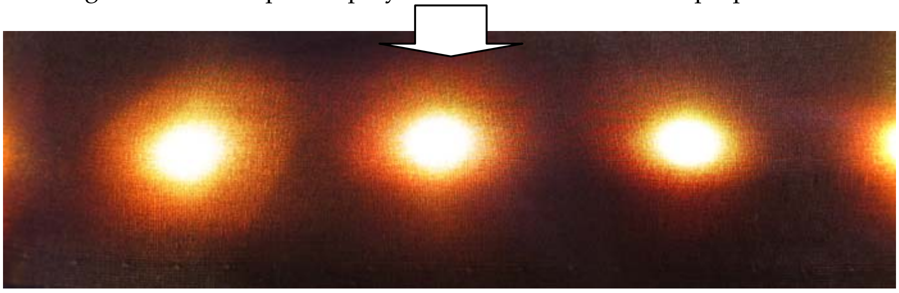


Figure 4-46d. Sample 2 of polychromatic effect after superposition.

➢ Method 3: Textural superposition

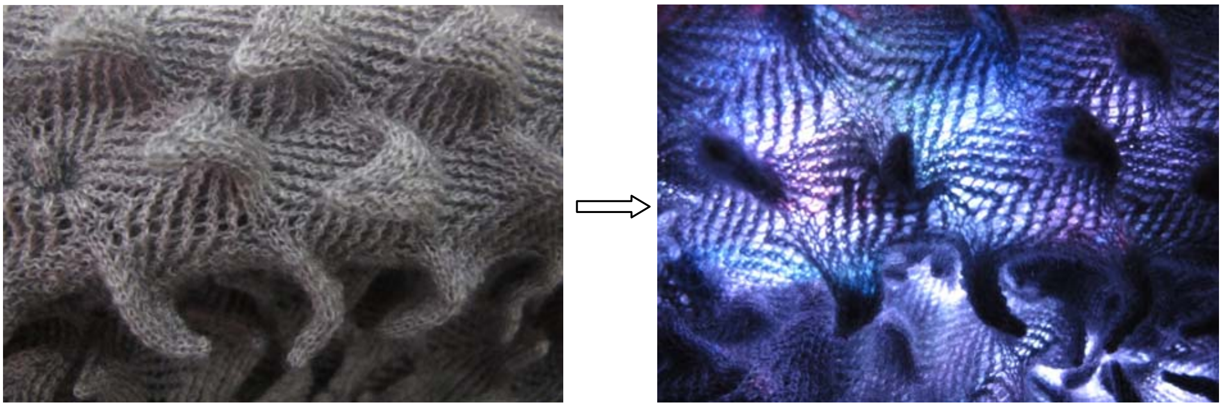


Figure 4-47a. Sample 1 of textural superposition.

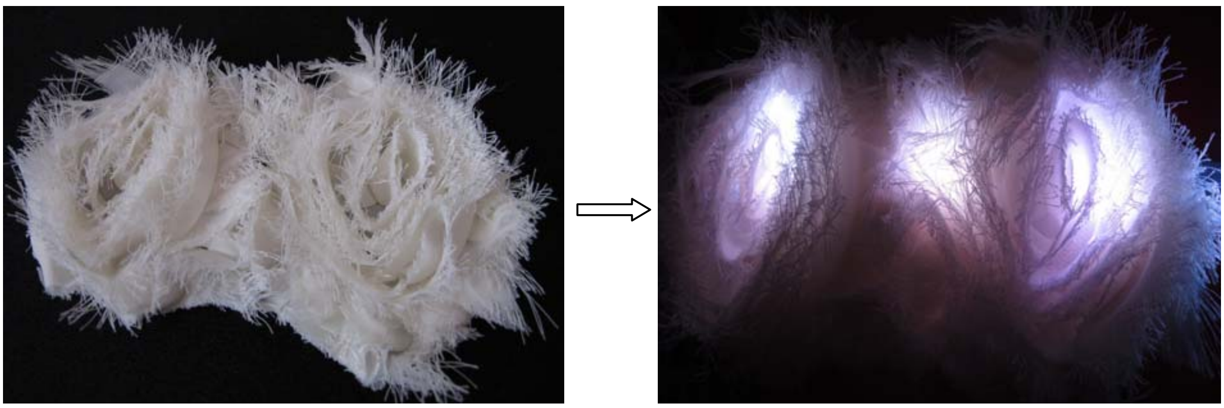


Figure 4-47b. Sample 2 of textural superposition.

Figure 4-47a and Figure 4-47b showed the detailed samples of textural superposition.

4.4 Exploration with Design Aesthetics of IF

This section deals with the overall aesthetics of the creations, with particular regard to the exploration and integration of the design of the four major aesthetic features of fashion design. The IF in this research is a multi-disciplinary product, i.e., integrating knowledge of psychology, electronics, fashion and textiles, and design aesthetics. Being a kind of wearable electronics relating to electronic technology, the display of IF often adopts relatively simple designs and with a strong technological overtone due to its constraints and the requirements of both technology and wearability. The innovative design approach adopted in this research aimed to enhance the technological creations by combining them with the aesthetics of fashion design yet with interactive electronic display functions. The following paragraphs indicate how this was achieved with reference to the four basic principles of fashion design, i.e., silhouette, texture, structure and details. (Kathryn and Janine, 2003).

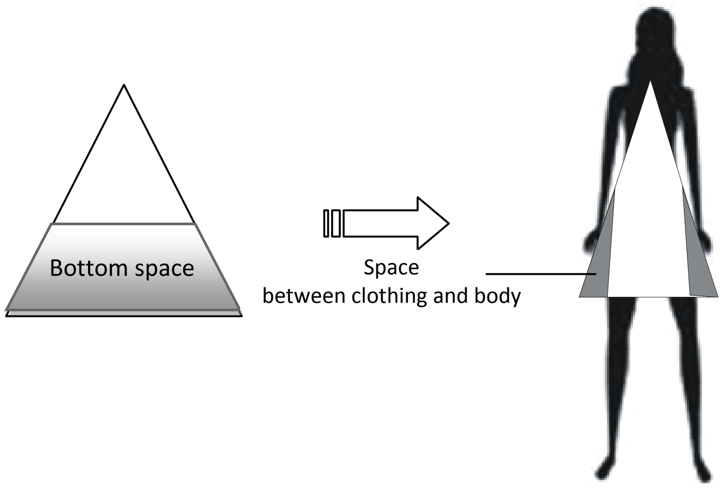
4.4.1 Silhouette

Silhouette is a major factor in fashion design. Each fashion item has only one silhouette which directly affects the configuration and style of the item (Kathryn and Janine, 2003). Various fashion styles have been categorized into basic shapes, of which the A shape, O shape and X shape have been adopted for this research. Based on these three shapes, the IF designs combined the basic design principles such as dot, line, area and shape with silhouettes that achieved optimal display expression and display effects.

▲ A silhouette:

Silhouette A is like a triangle shape from the top to the bottom (Kathryn and Janine, 2003). The gradually enlarged bottom part provides an area around the lower part of the body of the wearer which is suitable for the installation of LED and its accessories. The standard A silhouette can be further modified by different variations and combination. The following silhouettes suitable for IF are the result of different variations and combinations based on the original standard A silhouette.

The original A silhouette:



The original A silhouette can be developed into a symmetrical A, an asymmetrical A and combined A silhouettes. The variations in dot, line and shape are based on the original standard A shape for simple geometrical forms. The grey areas are interspaced between the material and the body of the wearer for installation of electronics. It also keeps the LED away from the shell fabric for a softer lighting effect.

▲ Symmetrical A silhouettes: Silhouettes which are symmetrical horizontally with a narrower top and a wider bottom.

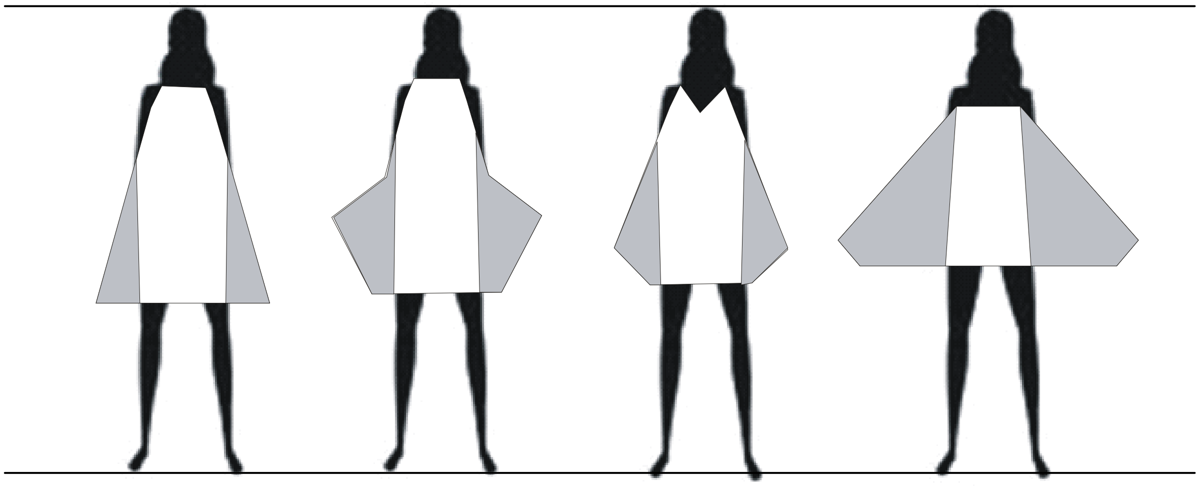


Figure 4-48. Variations of symmetrical A silhouette.

▲ Asymmetrical A silhouettes: Silhouettes which are asymmetrical horizontally with a narrower top and a wider bottom.

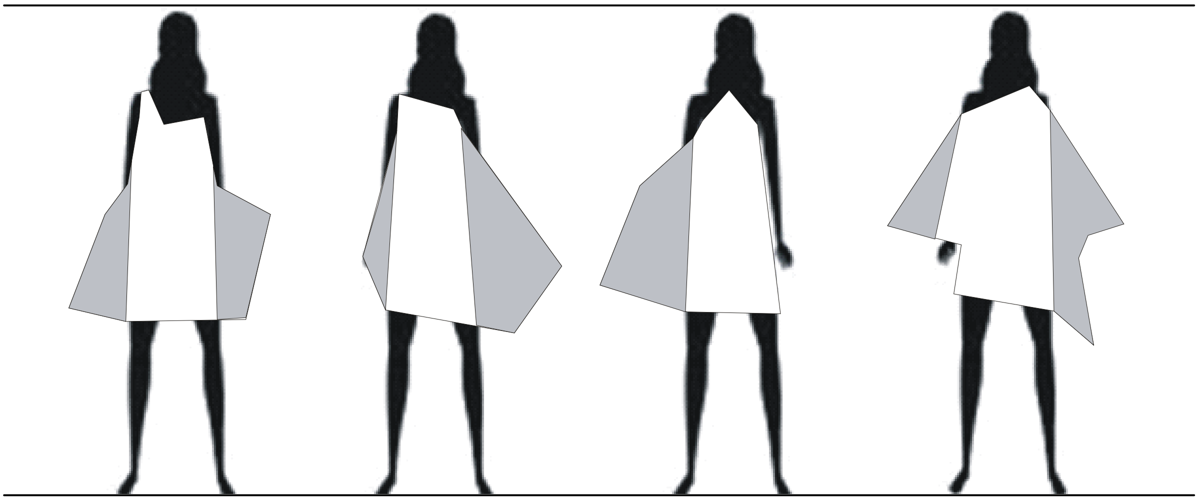


Figure 4-49. Variations of asymmetrical A silhouette.

▲ Combined A silhouettes: Silhouettes formed by a combination of various shapes in a silhouette with a narrower top and a wider bottom like the original standard A silhouette.

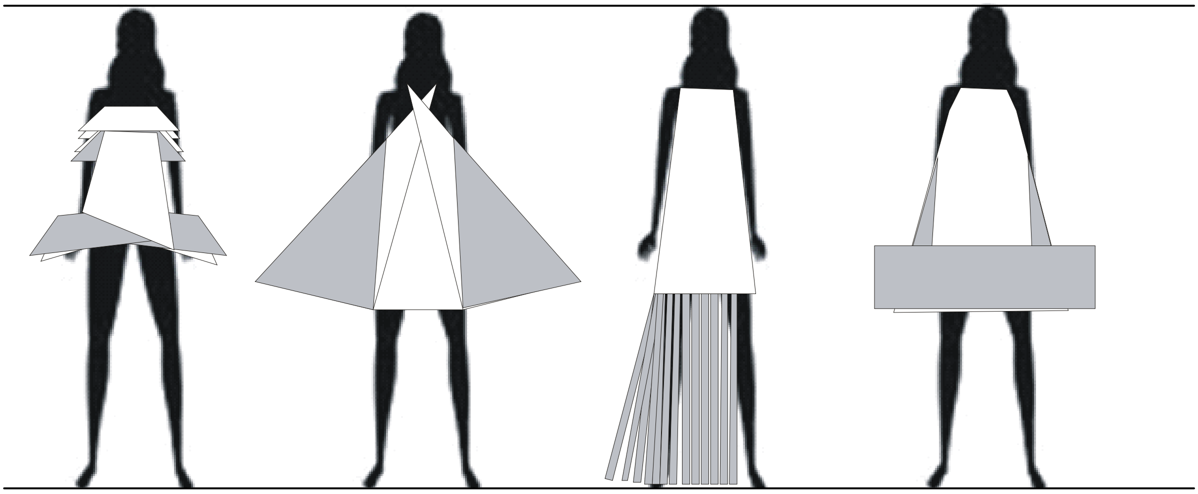
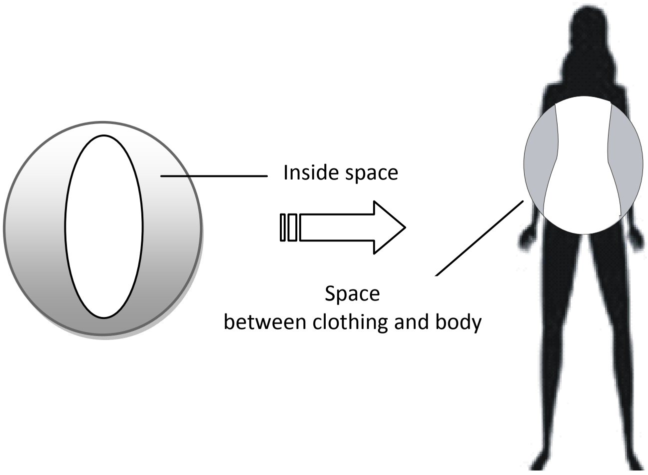


Figure 4-50. Variations of combined A silhouette.

- Silhouette O:

The O silhouette is round in shape (Kathryn and Janine, 2003). The original O silhouette is a perfect circle. It can be developed into oval shapes and bud shapes as long as they have rounded edges. For technological reasons, in the past IF tended to lend itself to more angular shapes. The O silhouettes help soften the convention of rigid technology and offer an alternative in terms of aesthetics. The O silhouettes also make IF design easier due to the space between the shell fabric and the body of the wearer.

The original O silhouette:



Based on the original O silhouette, the varied regular O silhouette and combined irregular O silhouette can be created.

- Varied regular O silhouettes: Silhouettes which are regularly varied from the original standard O silhouette.

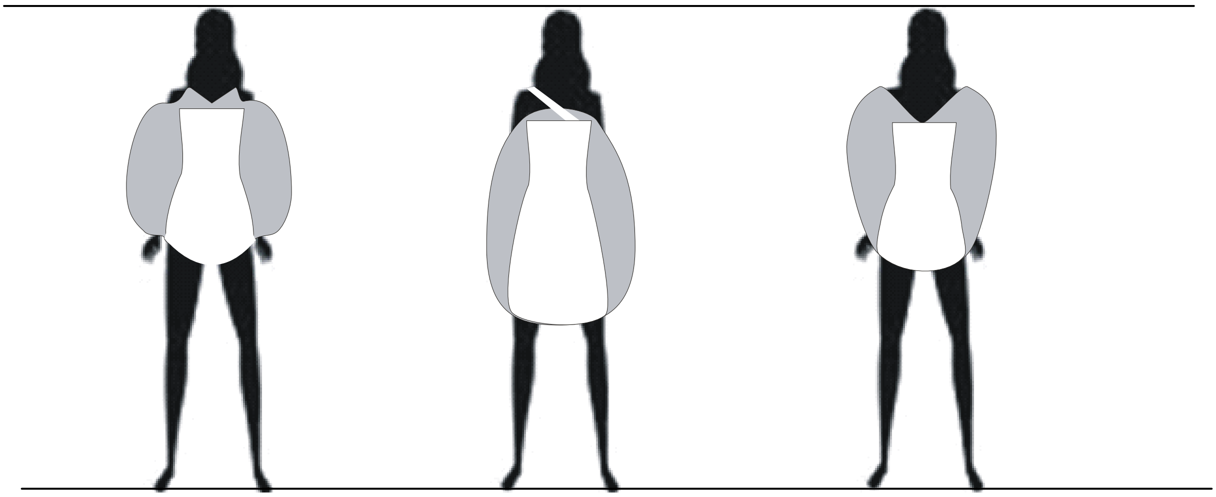


Figure 4-51. Variations of varied regular O silhouette.

- Combined irregular O silhouettes: Silhouettes which are formed by combining different rounded shapes irregularly. The grey areas are positions ideal for installation of LED, the voluminous shape is advantageous for optimal expression of visual effect.

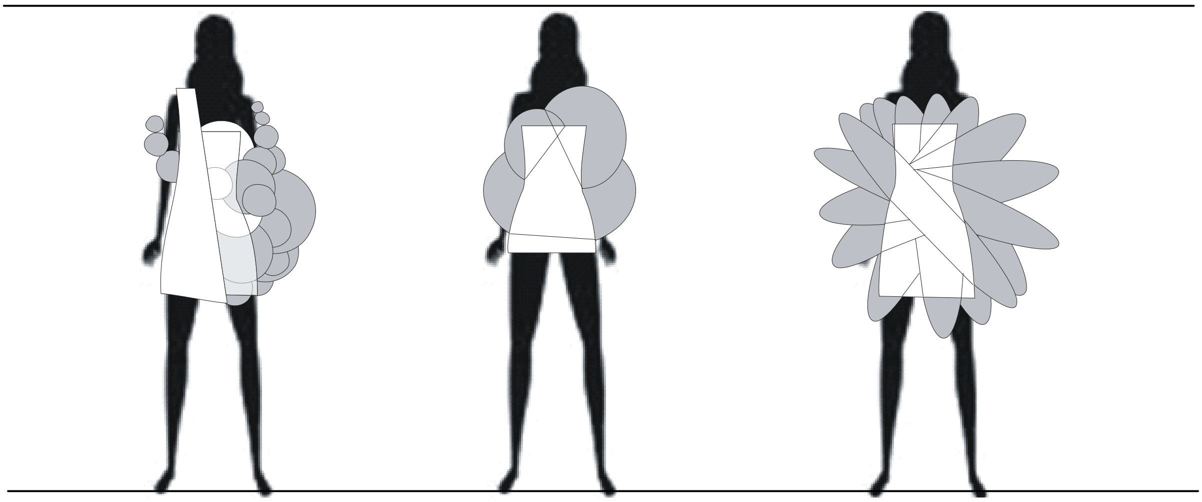
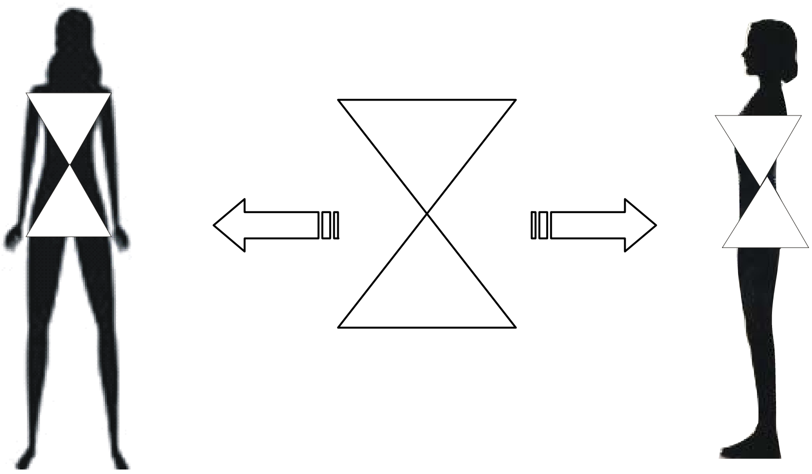


Figure 4-52. Variations of combined irregular O silhouette.

✖ Silhouette X:

A silhouette having both its top and bottom spread out horizontally and a narrower middle like the shape of an hour-glass. In fashion design, it is regarded as one of the most flattering silhouettes that enhances the elegance of a female body (Kathryn and Janine, 2003). Based on the original standard X silhouette, varied X silhouettes were developed in the hope of capitalizing on the elegance of the female body in IF design.

The original standard X silhouette:



The followi Applied in front re developed from the original standa Applied in side with the aim to increase the interspace and 3D feeling to fulfill the IF requirements. The grey areas are interspaced between the material and the body of the wearer as a result of different X variations for an enhanced IF visual effect.

- Symmetrical X silhouette: Silhouettes which are symmetrical horizontally and vertically.

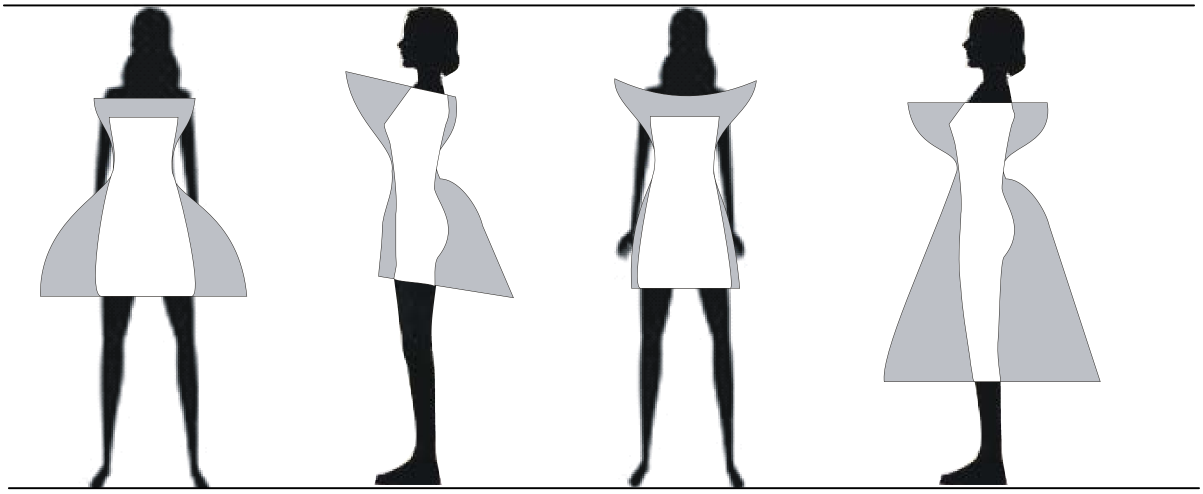


Figure 4-53. Variations of symmetrical X silhouette.

- Asymmetrical X silhouettes: Silhouettes that are asymmetrical add sense of drama and structure.

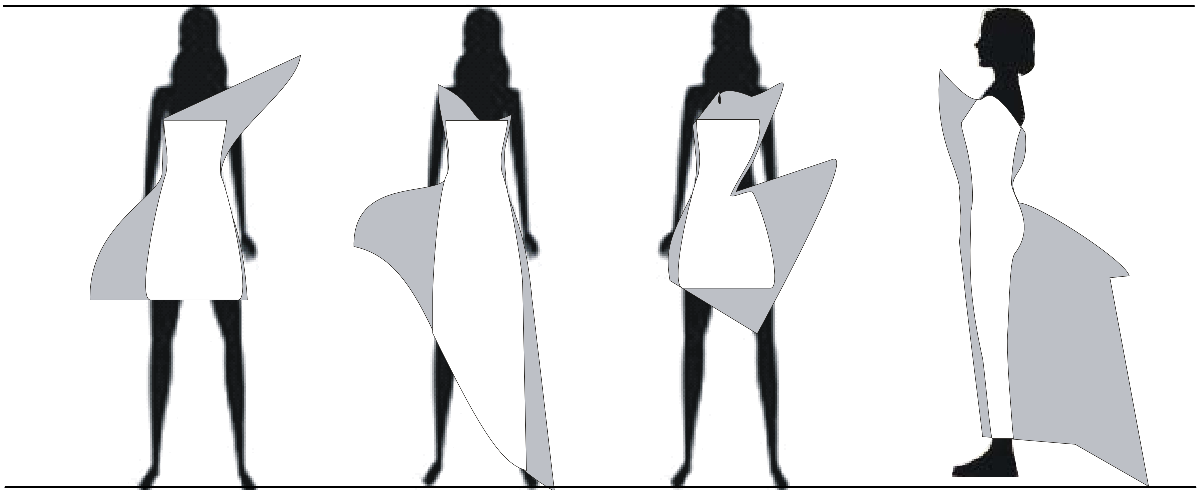


Figure 4-54. Variations of asymmetrical X silhouette.

× Combined X silhouettes: Silhouettes which are elongated as a result of repetitive combined X layers for a richer visual expression of LED effect. The grey areas are the positions ideal for the installation of LEDs.

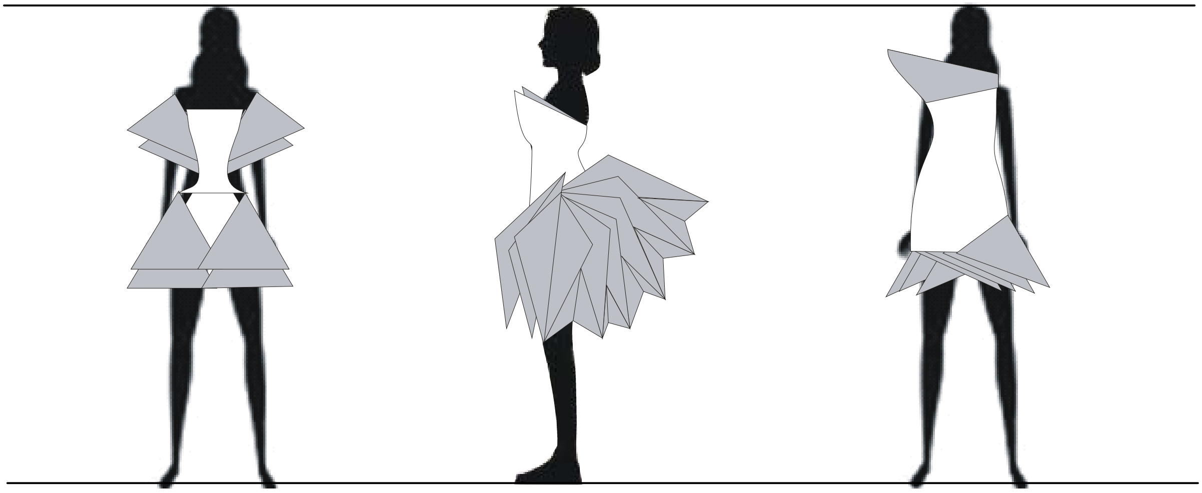


Figure 4-55. Variations of combined X silhouette.

4.4.2 Structure

The structure design of IF differs from that of fashion. In addition to the consideration of structure design of clothing, structure design which is peculiar to IF will also need to be taken into consideration, e.g., positions and areas for electronics installation, visual effect and comfort. These have made the structure design of IF more sophisticated than that merely for clothing and whose structure design as well as their respective considerations are worked out rather differently. Considerations will include exterior structure design, interior structure design and the interrelationship between exterior and interior structure design.

- Exterior structure design – expression of visual effect

The visual effect of IF in this study was dependent on those LEDs installed in the garment. Thus, the position and the manner of installation were important factors of consideration, i.e., the design of space of an exterior structure. From the spatial perspective, designs were conceived from 2D flat surfaces to 3D structures. Desirable space for optimal visual effect was created using 3D modeling techniques. The following indicate attempts made on the exterior structure design which primarily relied on the flexibility of the materials to create the required space.

Figure 4-56a. Sample of exterior structure design.

Figure 4-56b. Sample of exterior structure design.

- Interior structure design – design of electronics installation

The emphasis of interior structure design starts from basic Ergonomics (Tzou and Lu, 2009) and further combined with the basic clothing structure to create space for electronics installation of IF, e.g., position of battery, circuit boards such as main board and subpanels, wiring, positions of inputs and outputs, etc. Since these electronics are not fabrics, safety was also one of the considerations. Figure 457-a and Figure 4-57b showed the outline samples of interior structure design.

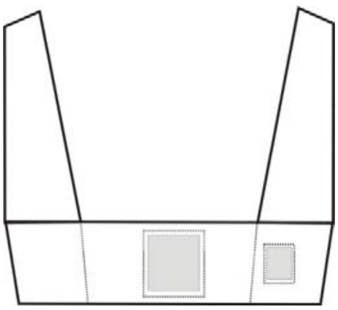


Figure 4-57a. Outline sample of interior structure design.

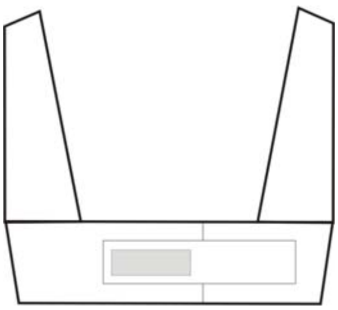


Figure 4-57b. Outline sample of interior structure design.

4.4.3 Texture

In fashion design, various textural effects can be created by means of different materials and handicrafts, and in turn rich exterior forms. Thus, research on application of texture in IF designs can widen up the scope of aesthetic expression. Texture design in IF can also be divided into exterior and interior. Exterior texture design is primarily concerned with visual expression and clothing aesthetics whereas interior texture design puts greater emphasis on wearing comfort and interior structure and interspace.

- Exterior texture

Exterior texture is evaluated for optimal expression of LED light effects. In Section 4.4.1, it was stated that LED can only change in color and intensity. For the visual communication in IF, LED alone may not be expressive enough. Thus, exterior texture design is to combine the conventional textural effect manipulation or redesign of fabric with the changing effect of LED lights. By manipulating the textural effect, a finer expression of LED lights effects can be achieved while at the same time the textural quality of the clothing item is being enhanced by the LED lights which glow from within whereby the visual effect of IF is enriched. Below is the process of redesigning exterior texture.

Figure 4-58a. Samples of exterior texture.

Figure 4-58b. Samples of exterior texture.

- Interior texture

Interior textile focuses on the selection of materials that are comfortable, of which the materials next to skin should be elastic enough to wrap around the human body, the sandwiched layer should offer good support and be of a certain thickness to minimize the sense of existence of any foreign matter.

4.4.4 Details

The overall macro-aesthetics of IF can be achieved through the three aforementioned aspects whereas the micro-aesthetics are addressed in detail. Through detailed treatment and alterations in terms of details of fashion, pleasant contrasts between large and small, simple and complicated, empty and full can be created. These contrasts offer rhythm and beat to the IF for an added visual appeal.

Figure 4-59a. Sample of detail design.

Figure 4-59b. Sample of detail design.

Figure 4-59c. Sample of detail design.

Figure 4-59d. Sample of detail design.

4.6 Summary

This chapter reported the practical component of the research carried out in this study. Several key creation elements and design requirements of IF were identified after an initial appraisal of feasibility, which included input and output elements, corresponding materials and devices, and IAP requirements. In the light of the appraisal results, the next stage of research was identified and selected. Through collection and analysis of primary data, an application platform for creative designs suitable for IF was made possible. Experiments were carried out to determine the best uses of electronics in IF; physiological data were obtained for feature extraction; physiological signals RSP and ECG (BVP) were selected as the sensorial inputs in this research by which a model of emotional recognition classification was established. The real electronic system design included hardware design, software design and LED program design. System hardware included input physiological signals conditioning, signal sampling, data transmission and storage, real-time clock, LED display, etc. There was a detailed analysis of the available hardware, and LED strips suitable for IF application were custom-designed. Various combinations of materials and LED were tested. Certain uncommon design methods of LED display were experimented with in order to identify the methods suitable for the incorporation of LED in garment. In the research on the subject of the overall effect, research on the design aesthetics of IF was conducted in an attempt to dispense with the conventional rigid and plain properties and appearance of IF. The silhouette, texture, structure and details of fashion were individually explored and deliberated in preparation for the following stage of innovative design and creation of IF.

CHAPTER 5

CREATIONS

The previous few chapters discussed IF research from theory to practical operation. In the theoretical research, a full understanding of the source of IF concept, design background and concept composition were acquired and a theoretical system for IF was established, which was subsequently applied to the actual designs for IF. The research into practical applications mainly involved experiments to determine the factors influencing emotion identification as well as trial explorations of IF related to materials, design methods and overall design validity in visual communication. These studies, experiments and explorations laid a solid foundation and ample creative space for realizing IF design and the fabrication of overall work. This chapter discusses the design and production process of IF finished products as well as the final outcome of the research.

5.1 Visualization

Creations of IF require not only careful, rigorous, comprehensive, in-depth and rational research and analysis, but also a return to perceptual creation and interpretation in fashion. However, being a means of creating concept clothing, it needs novel creative ideas, imagination and associated design content in addition to a practical technology platform. Irrespective of the type of designs, they must be 'people-oriented' (Steve, 2009). Human needs include both physical and psychological, physical and spiritual, and these needs are progressively shifting from simple to complex and from single to diversified, forcing designers to attend to some issues which had previously not been taken serious enough, such as mental anxiety and certain mental illnesses. Although these have traditionally been viewed as being in the fields of psychology or medicine, research on these issues will necessarily entail more interdisciplinary integration. This research on IF creation was instigated in with such problems in mind, mainly analyzing physiological responses generated by different emotions, using corresponding physiological signal data computing of these physiological responses to identify different emotions, and giving responses relative to these emotions through IF visual communication so as to create subtle interactive effects among people. Based on the results of the previous experiments, creation focused on the most basic human physical activities, i.e., breathe and heartbeat. Breath and heartbeat are the initial expressive physical signs showing the beginning of life of a person and accompanying the corresponding movements throughout his life. Although they are essential to daily life, people often neglect them because they are too natural and normal. Everyone will breathe, the heart will naturally beat, and blood will circulate on its own. In the busy modern society, if no problems arise most people will not pay attention to their breath or monitor their own heartbeats, not to mention to understand and adjust their emotions through them. In 3.4, substantial theoretical research on "emotion" was discussed. The findings can be broadly divided into two categories: positive and negative emotions. Positive emotion includes calmness, joy, etc. It can make people feel peaceful, optimistic, cheerful, and happy and can reduce the risk of heart-related diseases (Timothy, Kelly, John and Linda, 2004). Negative emotion includes sadness, anger, anxiety, excitement, etc. It can make people feel depressed and melancholy and will affect health, particularly lead to mental illness and cardiovascular disease. Therefore, it is particularly important for people to assess their physical and mental states by monitoring their breathing and heartbeat, to be aware their emotional state. Some people argue that it is impossible for a person not to know their own emotions. However, knowing and awareness may be different, for example, when a person experiences negative emotions he may attribute them to outside causes. He therefore finds ways to eliminate the negative emotions from the external world rather than his internal world. If he can sense the breathing and heartbeat irregularities at this time, what he should do is to make them return normal, which can gradually improve his emotional state. The IF innovative design causes the wearer to address his breathing and heartbeat irregularities through a strong visual display that presents real-time status and basic emotion recognition, enabling the wearer to turn his attention to the necessary remedial action, and create subtle human-clothing interactions. Besides, visual information transmitted by IF allows spectators to roughly understand the current physical activity of a wearer as well as the fundamental emotional state, and thus can act on the interactions between the spectator and the wearer. It follows that IF creative design is not merely on the surface of interactive technology or fashion design, but may be used to promote a healthy life attitude – shifting the excessive attention from the external world to the person's own inner world. The cycle begins with the subject watching and connecting with his own body, listening to his heartbeat, sensing his breath, and being aware of his emotions to generate a virtuous cycle of interaction. With specific reference to design aspects, the creative concepts of fashion forms were combined with detail treatment of high fashion and design concept was realized into fashion. In the IF design process, it was important to erase the stiff and cold impression given by the technology components of wearable electronics. When IF interaction does not occur the beauty of the clothing speaks for itself, whereas, when IF interaction occurs, the impression is subverted by the beauty of technology.

The following includes discussion of the design concepts, and the design and production process of the creations of IF, based on the two major physiological activities, i.e., 'breath' and 'heartbeat and pulse'.

5.2 Creation A: Based on 'Breath'

5.2.1 Design concept

In today's noisy, high-stress world, many of us sit, stand, sleep, speak, act, and move in ways that undermine our breathing and our physical, emotional, and spiritual health. Breath is defined in biology as the gas exchange process between an organism and the external environment and a physiological process in which people sustain life by exhaling carbon dioxide and inhaling oxygen; in the medical area, people's lung functions can be monitored through breath rate and waveform (Parkes, 2006); in physiology, breath rate and waveform are related to the emotional and physical condition of a person. In psychology, however, studies show that particular breathing exercises can greatly improve the physical and mental conditions of a person (Andrew, 1990). It can be seen that, our breath not only brings needed oxygen to the physical body, but it can also bring, when we are conscious of it, the finer energies needed to help nourish our higher bodies - the subtle body, causal body, and so on. Whatever we may believe about our soul and spirit, our breath, and how we breathe, is intimately connected with all aspects of our being.

Modern people's lifestyles and thinking habits have made most people's breathing shallow, resulting in disconnection with the body and failure to supply enough oxygen to the brain and body cells, which is not conducive to long-term physical and mental health (Mayo, 2010). Creation A – one of the design concepts based on "breath" is to make the wearer concerned about his current breath, pay attention to the issue of how to breathe in order to have more energy, and then create subtle interplay with IF through his own breath. As IF based on "breath" can present the breathing process via visual effects, it can help to promote and perform effective breathing exercises. Another design concept is to identify the basic emotional state of a wearer through breath rate and waveform, namely positive emotion and negative emotion. The wearer can change IF status display by adjusting his breathing. Based on the study of physiological signal parameters and emotional recognition discussed in Chapter 4, Creation A: based on "breath" applies techniques in the detection system for respiration to conduct overall system design so as to sense the real-time breathing process and identify the emotional state. Dress form was used in this creation. Combinations of external material shape and internal LED light color changes were used to reflect the effects of interaction, to convey technology performance and preserve the beauty of fashion itself at the same time.

5.2.2 Design process and procedures

5.2.2.1 Inspiration

The inspiration of IF interactive design came from the sense of rhyme of breathing itself and rolling rhythm, aiming to establish the subtle relationship of creating dialogue between the wearer's breathing and his body via IF. IF appearance design is inspired by shape of light and shadow in hollow patterns. Levels appeared when shadow moves and changes echoed with breathing air, creating a tranquil sense and naturally calming people down. The following are a few images of the inspiration of the creation.

Figure 5.1. The inspiration image of Creation A.

5.2.2.2 Design rationale

With reference to section 4.2.2 which contained results of the appraisal and selection, the form of the interaction process which was applied in further IF design is shown in Figure 5-2.

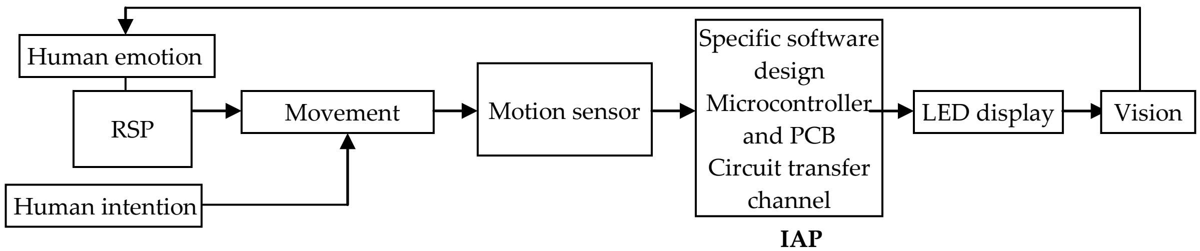


Figure 5-2. The interaction process applied into Creation A.

In the interaction process of Creation A, the 'input' is chest and abdomen movements induced by breath. The 'output' is LED display. The elements of the interaction process are listed in the following Table 5-1:

Input	Sensor	Processor	Actuator	Output	Relation	Level
Movement	Motion sensor	IAP	LED display	Vision	Human ⇄ Creation A [e]	Interactive [I]

Table 5-1. The elements list of the interaction process of Creation A.

The design for 'Based on Breath' included breath (respiration) rate, breath (respiration) depth and corresponding breath (respiration) wave. With reference to the research and analysis of acquisition of physiological signal data reported in section 4.3, the RSP measurement method was adopted to obtain respiration data from all aspects of Creation A for system design. RSP data was obtained by sensing and recording thoracic and abdominal movement waves caused by breathing. Sensing devices applied in Creation A were transformed from a thoracic and abdominal movement wave sensor. For thoracic and abdominal movements, one thoracic and abdominal expansion and contraction is regarded as one breath, i.e., expand when inhaling and contract when exhaling. This was used to record the respiratory rate per minute and respiratory depth status. The operation process of thoracic and abdominal respiratory movement wave sensor is shown in Figure 5-3.

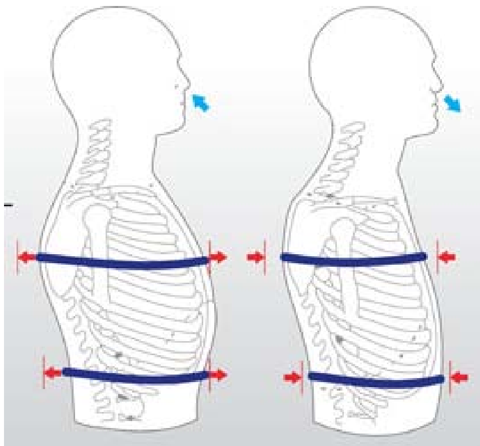


Figure 5-3. Operation process of thoracic and abdominal respiratory movement wave sensor.

According to the setting of the interaction process and the establishment of the input sensing mode, in order to visualize the process of respiration, the LED display of interaction modes needed to be further set. Interactive performance modes can be divided into real time monitoring and emotional state recognition.

- Mode 1: Real time monitoring

Real time monitoring is real-time sensing of thoracic and abdominal expansion and contraction produced when the wearer breathes with the help of thoracic and abdominal movement wave sensor through which respiration signals were obtained as input data and were entered into the electronic system of Creation A. According to both the design concept and design inspiration, the specific setting of the corresponding output presentation was the LED display that had the same shading gradient cycle as respiratory frequency and depth. The LED came on gradually when the wearer was inhaling; the deeper the wearer inhaled, the brighter the LED. Likewise, the LED gradually went off when the wearer was exhaling; the weaker the breath, the darker the LED. The cycle was a breath. In this mode, LED changes were controlled by the breath of the wearer.

- Mode 2: Emotional state recognition

Emotional state recognition is to give identification responses according to the respiratory wave status of wearer within a set period of time, i.e., taking records of respiration signal sensed by the thoracic and abdominal respiratory movement wave sensor in a set period of time as the input data to be entered into the electronic system of Creation A. The specific setting of corresponding output presentation is an extraction on the basis of the models of emotional recognition classification in 3.4.1.2 combined with features of physiological signals in 4.3.2. For example, when the wearer's respiratory status showed no obvious fluctuations and was maintained at normal breathing rate and waveform in the set period of time, the emotion was identified as being in a positive state, and LED would remain in the mode 1 presentation form. On the other hand, when the respiratory status of the wearer showed obvious fluctuations in the set time period, with the respiratory rate accelerated and respiratory waveform went dramatically up and down for instance, the emotion was identified as being in a negative state, and the LED would change its presentation form from relatively regular changes into irregular flashes to reflect the disordered breathing and unstable emotional state of the wearer.

The outline of interactive performance modes is shown as below:

Modes	Input data from sensor	Output presentation
Mode 1: Real time monitoring	Real time monitoring of Respiration signal	Gradual change of lights as same as the rhythm of respiration rate (Inhale – being light→ Exhale – being dark)
Mode 2: Emotional state Recognition	Record of respiration signal data within periods of given time	Regular changes → Irregular flashes

Table 5-2. The outline of interactive performance modes of Creation A.

5.2.2.3 Methods and principles of electronic design of Creation A

Based on the practical research which led to the electronic system design described in 4.3.3, the methods and principles of electronic design suitable for Creation A were extracted. Electronic design was set for IAP in the interaction process, i.e., processor, of which the major part is the electronic system and it includes settings of all circuits needed in the detection system and display system.

The main circuit design of electronic system of Creation A is shown below:

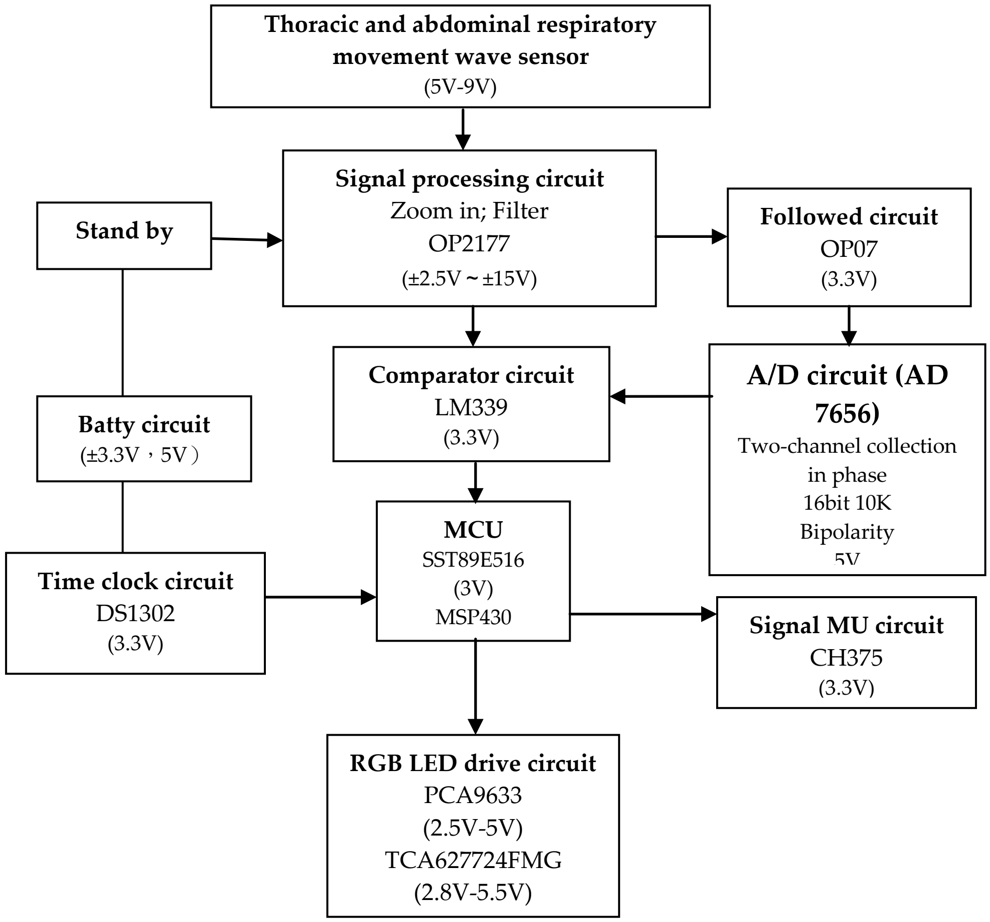


Figure 5-4. The outline of the main circuit design of electronic system of Creation A.

The operating principle was as follows:

The respiratory physiology signals of wearer were acquired by the thoracic and abdominal respiratory movement wave sensor, then the measuring data were sent to signal processing circuit. Weak signals output by the sensor amplified and noise was filtered out by processing circuit. Square wave pulse measured signals given by the processing circuit were turned into required double frequency pulse output signals by rate followed circuit. In this way, better frequency following effects could be achieved and the sampling accuracy could be ensured even when changes occurred to frequency of periodically-measured signals. Analog signals were turned into digital signals by the A/D converter circuit. Signals given by the A/D circuit were compared with set values by comparator circuit and the difference between them was indentified. This difference was outputted to the MCU by the end of comparator circuit, and the program stored in the MCU works based on this difference. For example, when the compared results between sensor-collected data and the set value were normal, on the one hand, the signal was transmitted to the clock circuit by MCU and time information fed back by the clock circuit was saved into signal MU circuit, and on the other hand, the signal was transmitted into the RGB LED drive circuit by the MCU program. Major parts in the entire electronic system are the RSP signal circuit program, MCU circuit program and LED program design.

The MCU is at the heart of this system. It is responsible for the coordination and data processing of each of the modules. As emotion recognition involves a great number of parameters, substantial matrix computing and frequency domain analysis were required. To this end, a hardware structure with quick computing speed, light weight, low power consumption, low heat productivity, and small storage space was required. The most suitable model was considered to be ARM + DSP as structure and OMAP of TI as platform to design a compact PCB. Figure 5-5 shows the MCU circuit.

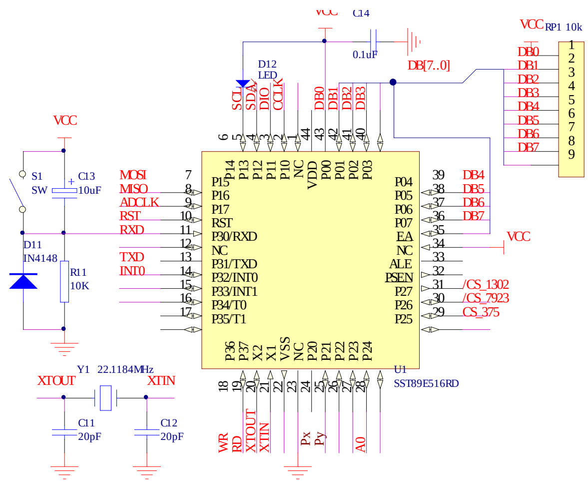


Figure 5-5. MCU circuit diagram.

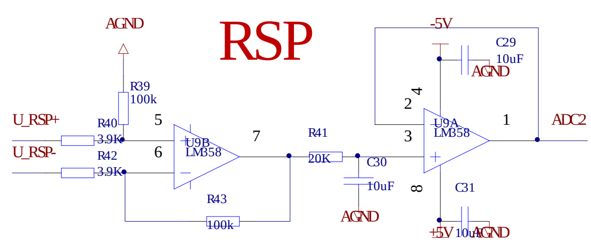


Figure 5-6. RSP measurement system circuit diagram.

RSP reflected respiratory rate and depth and its frequency range was 0-0.35Hz. Sensors were fixed at the chest and abdomen of the human body and by such the tensile force changes of chest contraction could be detected, with the output being directly proportional to respiration depth. The signal processing circuit first amplified the respiratory signal output difference by 25.6 times. The RSP signal could effectively remove power frequency interference and interference of high frequency myoelectricity through a low pass filter with a cut-off frequency of 8Hz after the difference amplifier.

In the LED program design, as described in section 4.3.4, the 4-bit LED drive through IIC bus-mastering was selected. It specifically optimized mixed application of red/green/blue/amber (RGBA) colors. In independent luminance adjustment mode, each LED output had an individual PWM controller of 8-bit resolution (256 levels) and fixed frequency. It could set the LED at a specific luminance value and dynamic light changes were by system programming. Since the system selected 10-pin package to provide two address lines only, the system could only have a maximum of 4 LED light panels installed.

The electronic system supported the following two modes. In different applications, writing their respective programs through the same hardware platform realized switchover selection of these two modes.

- On-line detection mode - when the system was connected to the upper computer, the measured physiological signals were sent in real time to the upper computer through the serials, the current emotion was sent back to the lower computer after emotion recognition, and corresponding LED lights were driven to show the current emotional state.

- Off-line measurement mode - when the system was not connected to the upper computer through serials, real-time physiological signals were recorded by the system and clock information and read data in the U disk was stored into the upper computer when convenient.

5.2.2.4 Integration and production of Creation A

After the deliberation of the above-mentioned design concept, design inspiration, design illustrations, design rationale, etc. and their respective settings, a specific production process was implemented in each part of the practice.

The production process includes:

✓ Redesign materials of 'Breathing Dress'

Based on the results of the experiments and tests in the section entitled Explorations and Experimentations of Materials and Design Methods, materials used in Breathing Dress were determined and re-design was needed to echo the design inspiration. Because of the special nature of IF, materials were divided into inner, middle and outer layers. The inner layer, being closest to the body, was of optimal tactile and skin friendly properties. Cotton and Lycra texture of medium thickness and good skin suitability as well as good flexibility were selected since the sensor was to be located close to the body. Thick leather as well as thin and permeable silk chiffon were selected for the middle layer because the former was of better load bearing capacity and flexibility while the latter softened the LED light color. A combination of resin materials and leather was used as the outer layer. A hollow technique was adopted to allow LED light to create the effects of inspiration light superposition.

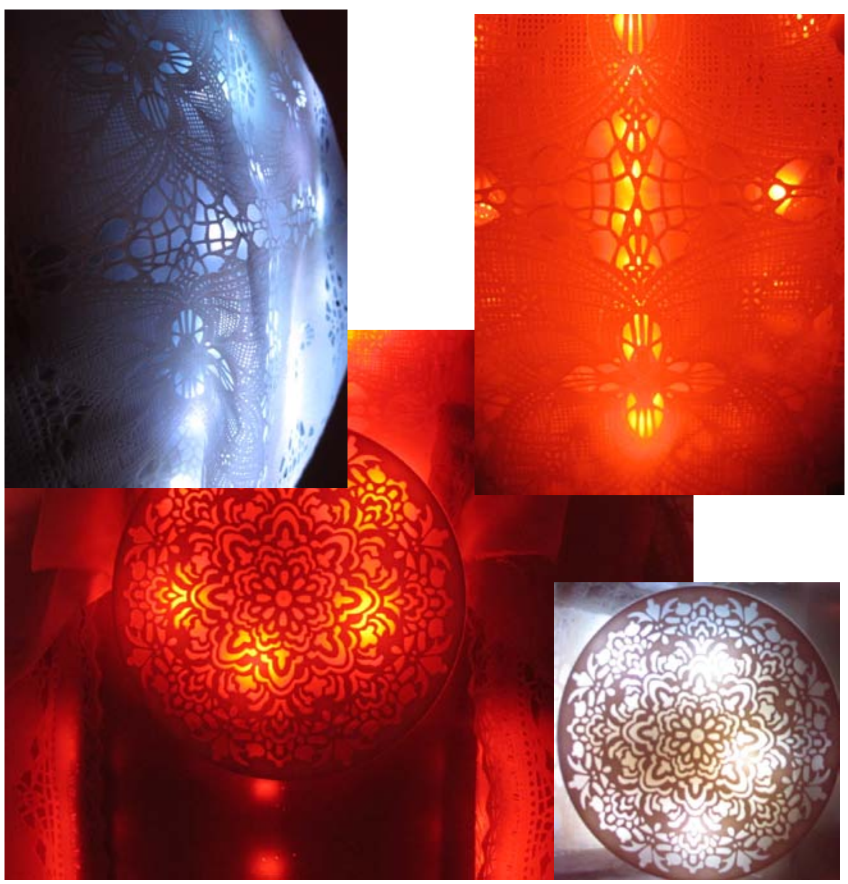


Figure 5-7. Redesigned materials samples of 'Breathing Dress'.

✓ Arrangement of electronic components and circuit distribution

Distribution locations of the electronic components and related circuit arrangement were determined according to design locations and practical operations, with the security measure of waterproof thermal insulation. The stress points of the various body parts were determined from an ergonomic perspective to ensure that the placement of electronic components would not affect the feeling of the wearer when wearing the creation. It can be seen from Figure 5-7 below that the inner layer of the dress was built with a tight vest. The vest was placed inside the thoracoabdominal respiration wave movement sensor as well as the main board and subplate of the electronic system, with the sensor being placed in front of the vest (near the chest) to facilitate sensing physiological signals while the main board and subplate were placed in the rear vest (body back center) for wearing comfort. The electric power source (battery) was placed on the shoulders with thick pads to reduce load-bearing. A total of 65 pieces of independent RGB LED were distributed in the front piece of the dress. In the circuit arrangement, guide wires were orderly arranged and fixed along the dress structure with concealed hidden lines. To ensure the safety of IF, waterproof and thermal and electricity insulative materials were added to the surface of all electronic components. All wires were insulated.

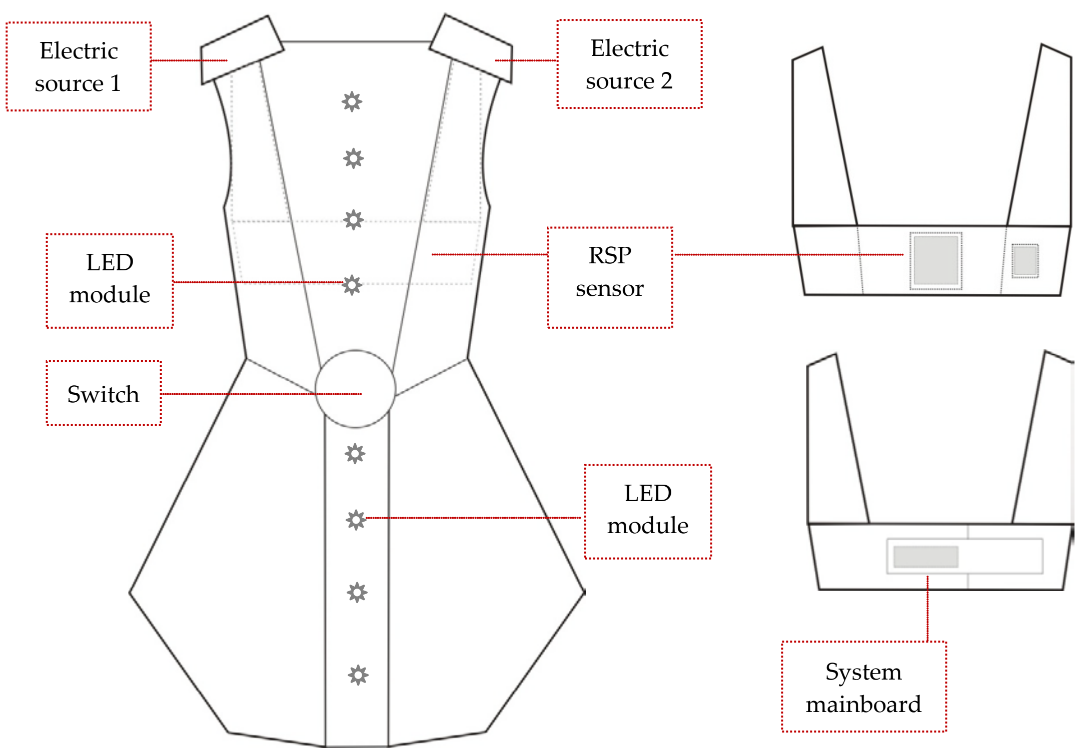


Figure 5-8. The outline of electronic components and circuit distribution of 'Breathing Dress'.

✓ Manufacture by 3D modeling

The 3D modeling technique was deployed based on Exploration with Design Aesthetics of Interactive Fashion and combined with design illustrations. After what had been done as described in the above two sections, this part was mainly involved organizing and sewing the inner, middle and outer layers of the dress together and debugging the previous settings in accordance with the actual results. After the basic shape of the dress was formed, detailed processing and handling followed to ensure that the whole 'Breathing Dress' reached the expected effects and beauty of the initial design concept and design inspiration.

Figure 5-9a. The detail of 'Breathing Dress'.

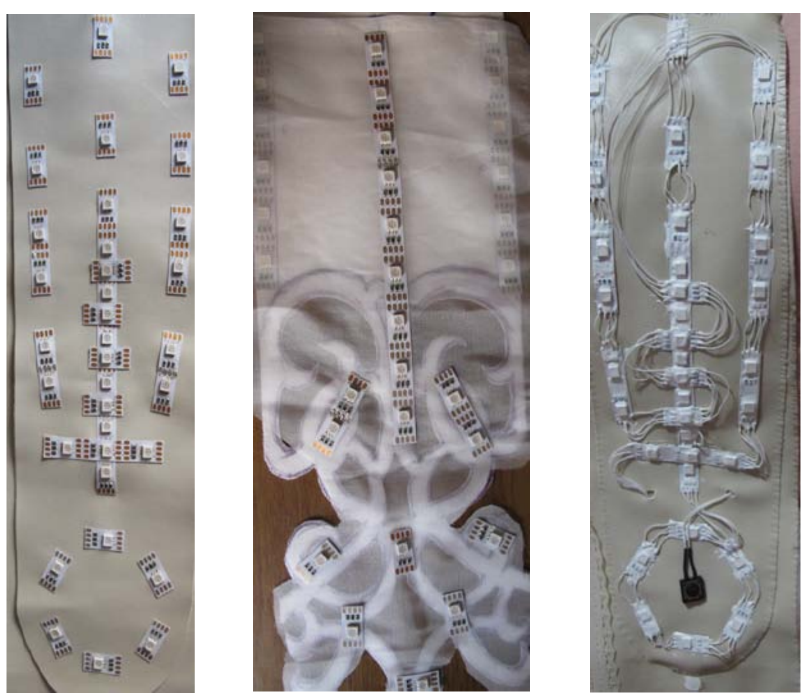


Figure 5-9b. The detail of 'Breathing Dress'.

5.2.3 The creation: 'Breathing Dress'

Figure 5-10a. 'Breathing Dress' before interaction.

Figure 5-10b. 'Breathing Dress' before interaction.

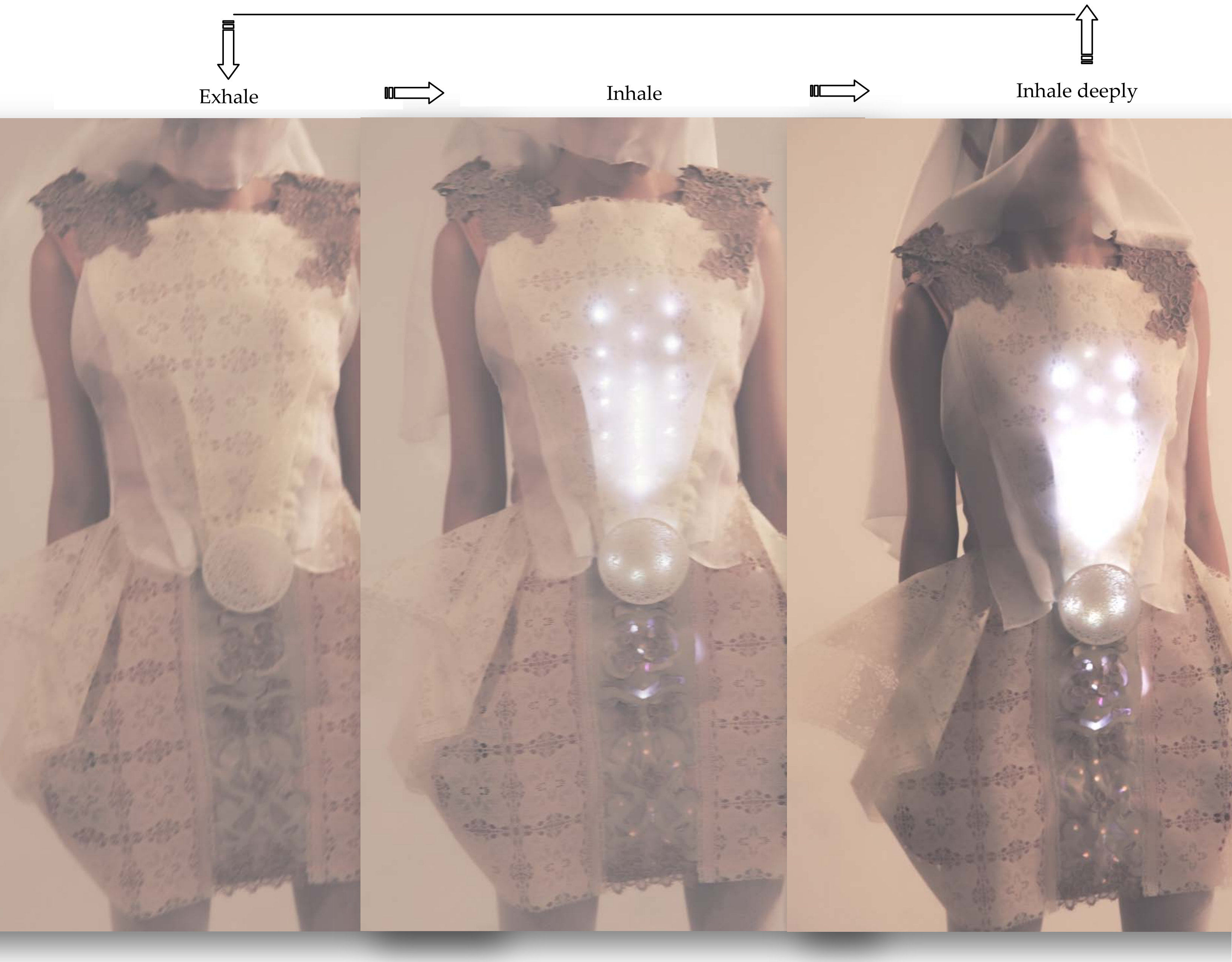


Figure 5-11a. The real expression of interaction process of 'Breathing Dress' in white.

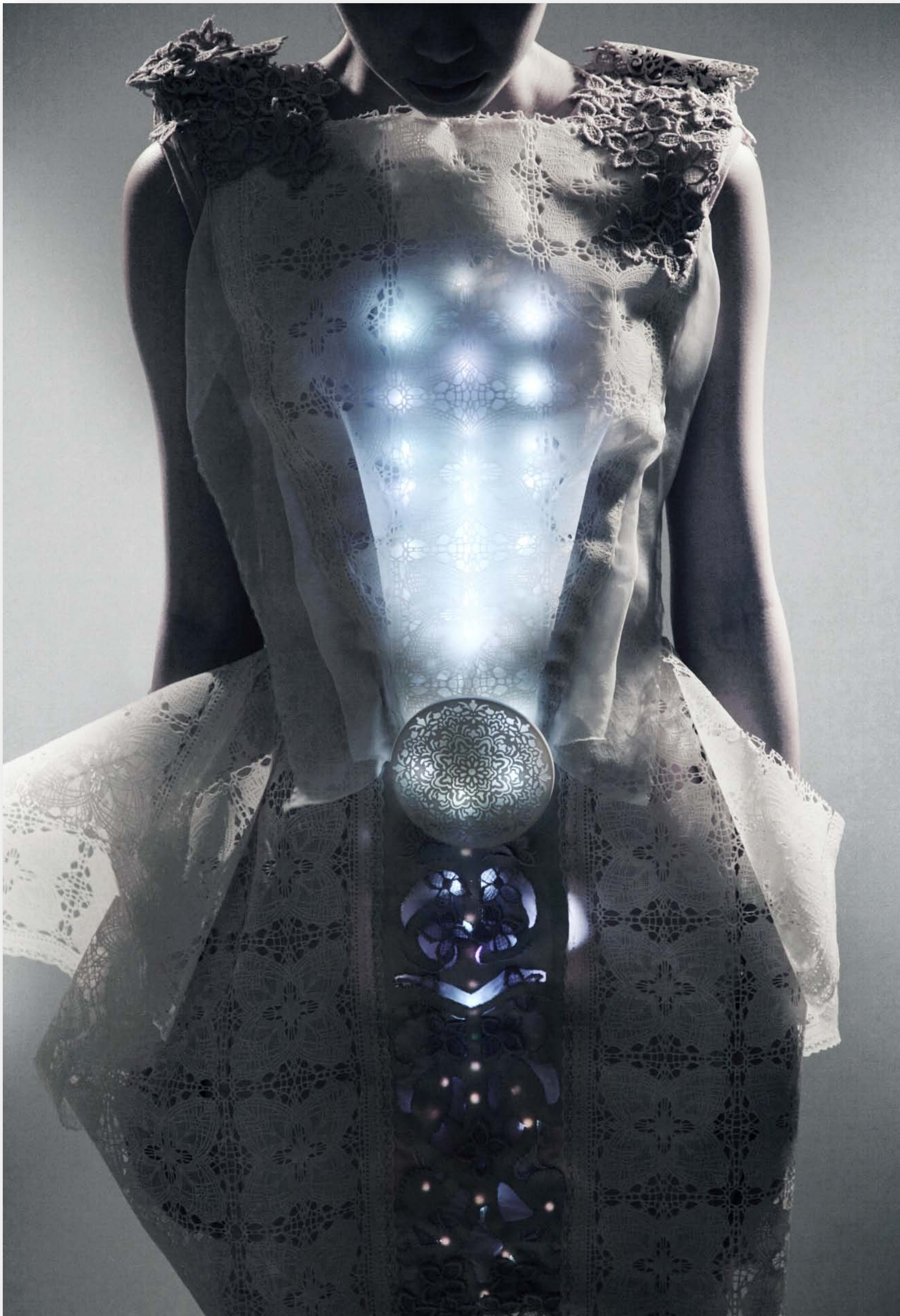


Figure 5-11b. ‘Breathing Dress’ turning on via wearer’s breathing.

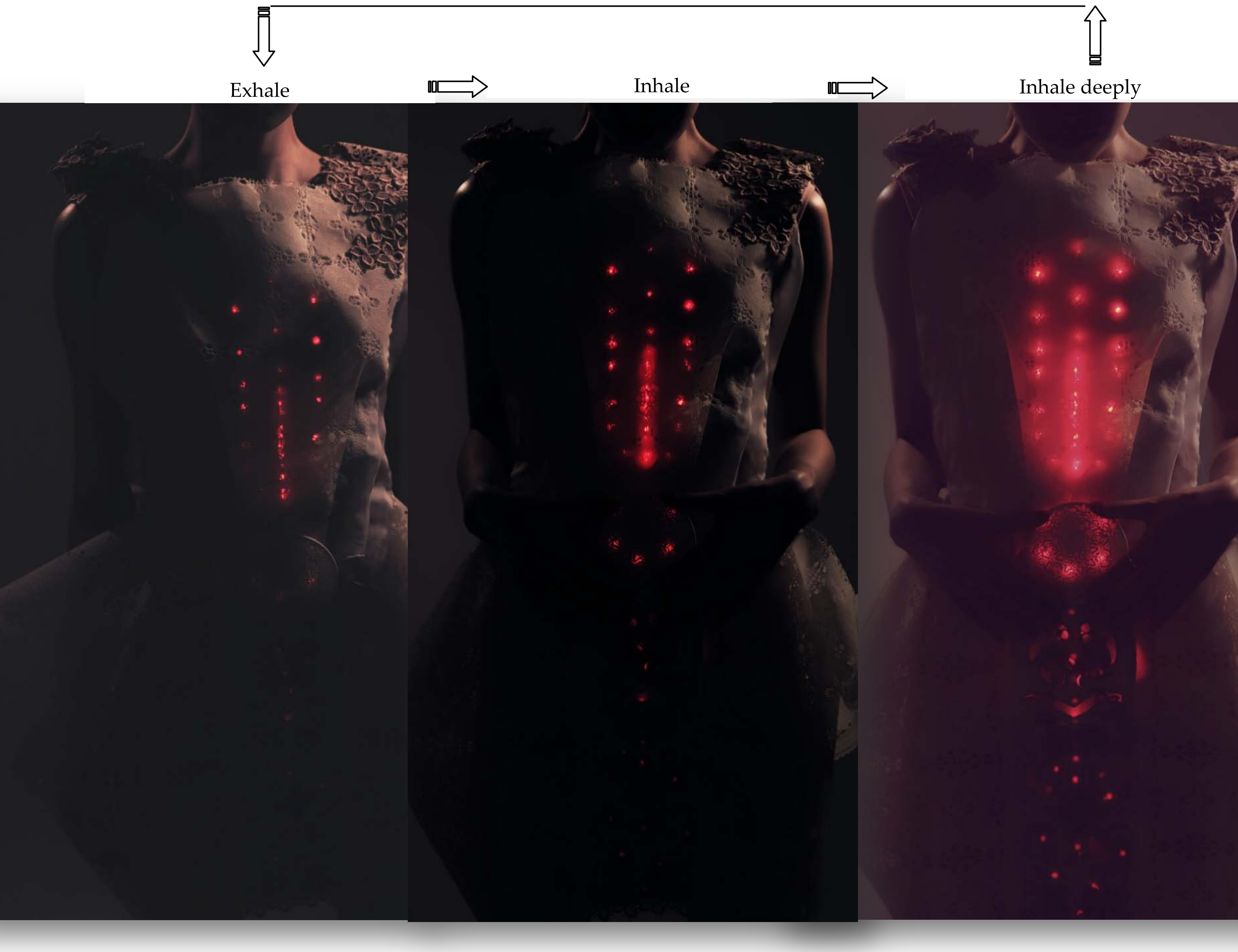


Figure 5-11c. The real expression of interaction process of 'Breathing Dress' in red.

'Breathing Dress' offers choices of color lights for wearer to signal her current emotion state. For instance, when the wear was in bad mood, she could choose red color light to suggest her current emotion state to spectators without saying it.

5.3 Creation B: Based on 'Heart & Pulse'

5.3.1 Design concept

Creation B took sensing the heart beat state of the wearer, i.e., pulse beat, as the basis for design. Under normal circumstances, the heart beat and pulse beat of normal people are the same. The pulse is a peripheral arterial pulse caused by the cardiac impulse wave passing through the blood vessels. Therefore, in Creation B, heart rate physiological signal and pulse rate physiological signal were input as the same sensing data. From the viewpoint of physiological functions, the heart is central to the maintenance of human life and the cardiovascular system serves as the 'visible heart' of which its rate can, to some extent, reflect the physical condition of a person (Vinken, 2000). In psychology, the 'invisible heart' refers to the spiritual world and emotional expression of a person. Although the 'invisible heart' is not substantive, it has a profound impact on the 'physical heart', which is the impact of emotion and the physiological responses of people discussed earlier in this work (Philip and Ann, 1994). It is by now a known fact that the emotion of a person does change his physiological signals. Positive emotion will play an optimizing role in balancing physiological signs, protecting the heart and other cardiovascular organs, and then impacting on the emotions to form a virtuous circle; on the contrary, negative emotion will upset the order of physiological signs. Long-term accumulation will be harmful to physical and mental health, cardiovascular function in particular, and forms a vicious circle. Recent medical studies have confirmed that when our emotions change, the brain will transmit the signal to the heart and the heart will express it in very complex forms, of which heart rate is the form more widely known. Heart rate not only reflects problems of the heart itself, e.g., heart rate being too fast, too slow or irregular, etc., but it also conveys certain psychological information (Timothy et al, 2004). The heart activity, as measured by pulse wave, e.g., comprehensive information about waveform, strength, speed, rhythm, is also rich in dynamic information. Therefore, to a certain extent, direct acquisition of heart rate related signals can be replaced by acquiring pulse rate related signals. The creation drew its inspiration from what is called "heart & hand connection" (心手相連), reflecting that design of Creation B started from “'heart & pulse”. Soft colors would still be used to reflect the color with humane care; emphasis was placed on the location of hand and heart through style and details. Skirt body and hand position used deployed extensive handicraft to create an aesthetically appealing creation.

5.3.2 Design process and procedures

5.3.2.1 Inspiration

Figure 5-12. The inspiration image of Creation B.

Inspired by "heart & hand connection", Creation B drew inspiration from the image of the white rose which represents purity and romance and the shape of heart as a start of the creation for "heart". On sensing pulse from a person's fingers, the white rose petals light up and turn into different colors of "roses" when the wearer's emotions change.

5.3.2.2 Design rationale

According to section 4.2.2 which elaborated on the Results of the Appraisal and Selection, the form of the interaction process which was applied in further IF design is shown in Figure 5-11 below.

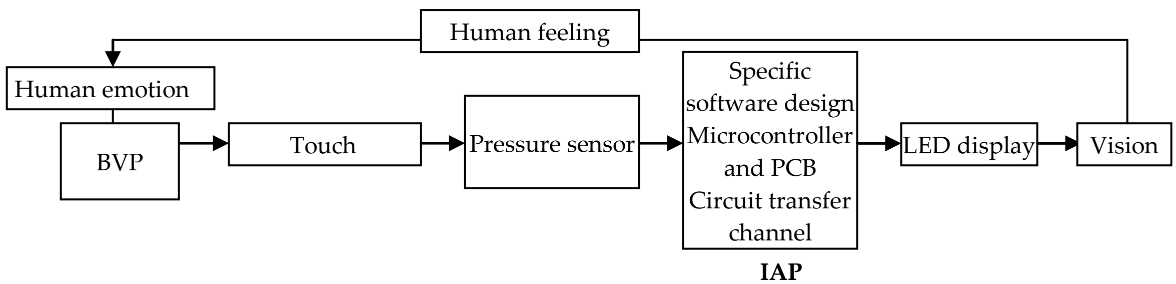


Figure 5-13. The interaction process applied into Creation B.

In the interaction process of Creation A, pulse waves of the heart beat/pulse beat were identified as the input. As pulse waves generated very slight vibrations, they were recognized as touch. The LED display was the output. Table 5-3 lists all the elements of the interaction process.

Input	Sensor	Processor	Actuator	Output	Relation	Level
Touch	Pressure sensor	IAP	LED display	Vision	Human ⇄ Creation B [e]	Interactive [I]

Table 5-3. The elements list of the interaction process of Creation B.

Heartbeat rate and pulse rate are the same, and pulse wave referring to the volume change and vibration phenomenon resulted from transmission of heart beat as the source of power through the vascular system. When the heart contracts, a considerable amount of blood runs into the aorta which is already full of blood, propping open the elastic vessel wall, then the heart turns the functions of blood into vessel elastic potential energy; when the heart stops contracting, the part of expanded vessel also contracts and drives blood to flow forward, resulting in vessel wall expansion of previous vessels. By parity of reasoning, this process and fluctuation is somewhat similar to spread in elastic medium. This proves that parts of the human body where pulse signal parameters can be measured are optional (Li and Barreto, 2003). Therefore, Creation B could obtain heart rate data by acquiring pulse rate data through the BVP measurement method according to the settings of the electronic system design discussed in section 4.3.3, where it was stated that BVP reflects the blood pressure and the pulse wave of a pulse. The finger tip, where both the flexibility and sensitivity are high, was selected as the place to acquire BVP physiological signals, and BVP photoelectric sensor located close to the finger shot red light on the skin surface to calculate the size of its reflective red light which was related to changes of subcutaneous blood flow, while changes of blood flow formed blood volume pulse from which the pulse rate was measured. Figure 5-12 shows a photoelectric finger-tip movement pulse wave sensor as BVP sensor applied in Creation B.

Figure 5-14. Photoelectric finger-tip movement pulse wave sensor.

According to settings of the interaction process and the establishment of input sensing mode, further setting of LED display of interaction modes was needed to visualize heart/pulse rate. Similar to Creation A, interactive performance model was divided into real time monitoring and emotional state recognition.

Mode 1: Real time monitoring

In the mode of real time monitoring, the pulse signal was the input data collected, including pulse rate and pulse strength degree. The acquisition timing unit of acquiring physiological signal data through BVP sensor on the finger tip was one minute. Within the acquisition time, output presentation was expressed as real-time pulse rate rhythm and LED light and dark beating with the same degree of strength. Upon the completion of the acquisition process, the display program was switched to Mode 2.

Mode 2: Emotional state recognition

Mode of emotional state recognition was performed on the basis of Mode 1. The pulse signal data acquired in a minute in Mode 1 was taken as the input data. It was seen from the secondary data research that the normal human heart/pulse rate is within the range of 70/min-100/minute. The range level of pulse rate data record acquired in Mode 1 was discriminated according to the five levels of pulse rate value set in the system program, i.e., i) pulse rate <70/min, ii) 70/min <pulse rate ≤ 80/min, iii) 80 <pulse rate ≤ 90, iv) 90 <pulse rate ≤ 100, and v) pulse rate> 100. Different range level values corresponded to different LED light colors. The Figure 5-13 shows the LED color values of five different corresponding range levels. This discriminated light color remained for one minute. Upon completion, it was re-switched to Mode 1 for real time monitoring.

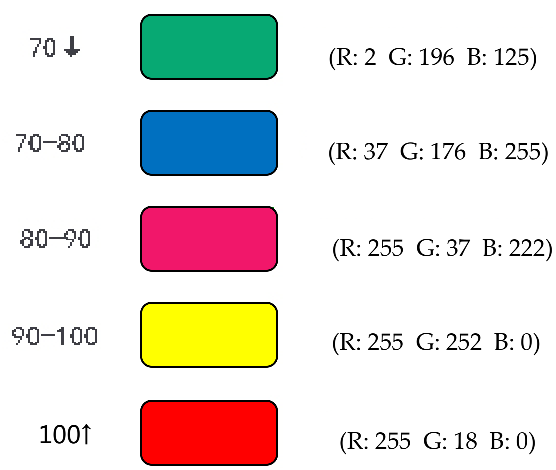


Figure 5-15. LED color values of five different corresponding rage levels.

When i) pulse rate <70/min, ii) 70/min <pulse rate ≤ 80/min, and iii) 80 <pulse rate ≤ 90, pulse wave is regular, pulse strength is moderate, being capable of representing a positive emotion, emotional state recognition in Mode 2 interpreted this as being in a state of joy-peace whereas when iv) 90 <pulse rate≤ 100 and v) pulse rate > 100, with pulse rate showing obvious sudden increase, this state could be identified as a state of negative emotions such as tension, anxiety, anger, excitement, etc.

The outline of interactive performance modes is shown in Table 5-4 below:

Modes	Input data from sensor	Output presentation
Mode 1: Real time monitoring	Real time monitoring of Pulse signal	Light and dark beating as same as the real-time pulse rate rhythm and strength degree
Mode 2: Emotional state Recognition	Record of pulse signal data in one min	Display LED light colors corresponding to the range levels of pulse rate in one minute

Table 5-4. The outline of interactive performance modes of Creation B.

5.3.2.3 Methods and principles of electronic design of Creation B

Methods and principle of electronic design suitable for Creation B could be extracted according to Practical Research of Electronic System Design in 4.3.3. Although the general framework of the electronic system is similar to that of Creation A, input data acquired by the system was completely different, and so were the sensor settings, thus the software design was completely different. The main circuit design of Electronic system of Creation B is shown in Figure 5-14 below:

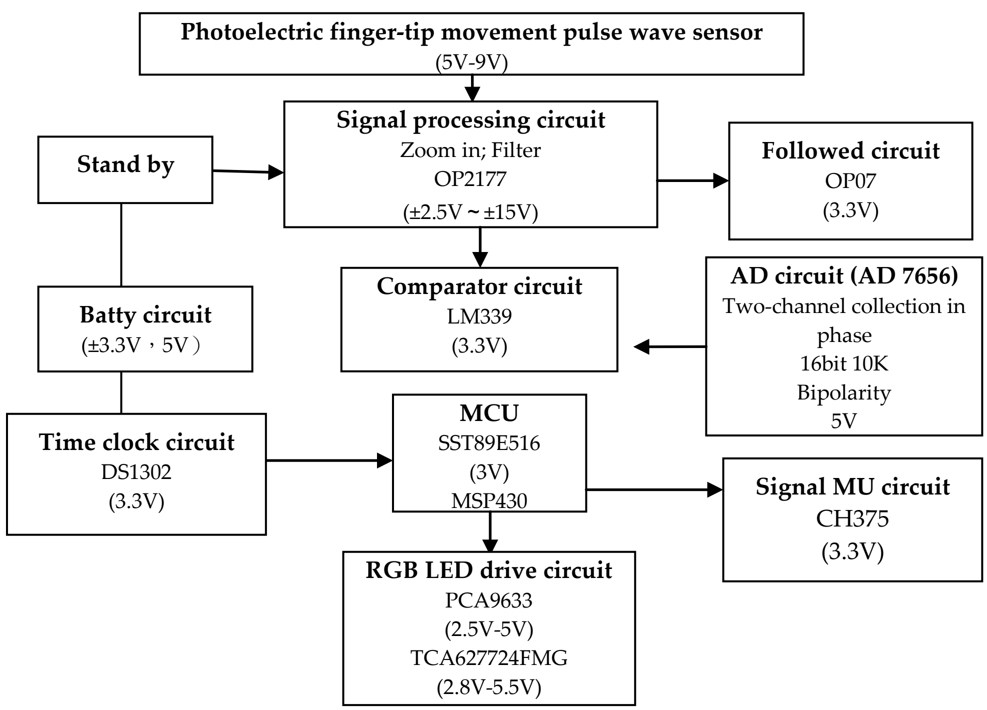


Figure5-16. The outline the of main circuit design of electronic system of Creation B.

Physiological signal data acquired through the BVP sensor was performed with BVP physiological signal conditioning via built-in programs in the signal processing circuit. The circuit operating principle is as follows:

The wearer's physiological signal was obtained by acquiring related data through the BVP sensor, specifically the photoelectric finger-tip movement pulse wave sensor with which the data was sent to the signal processing circuit. Weak signals output by the sensor were amplified by the processing circuit when unwanted noise was filtered out. The square wave pulse measured the signals output by the processing circuit which was turned by rate followed circuit into the needed frequency doubling pulse output signals by which excellent frequency following effect was achieved. The sampling accuracy could still be ensured when the periodic measured signal frequency changed. Analog signals were changed into digital signals by the A/D converter circuit. Signals and set values given by the A/D circuit were compared by comparator circuit, with the standards of set values as the limits. The difference discrimination was sent to the MCU by comparator circuit output end, where work was performed on the basis of the difference discrimination by the programs stored in MCU. For example, when data records acquired by the sensor were compared with set values, the comparison results located the respective range of signal data within the set values. On one hand, signal was sent by MCU to the clock circuit and was stores together with the time data fed back by the clock circuit into signal MU circuit while on the other hand, the signal was sent to the RGB LED drive circuit by MCU program.

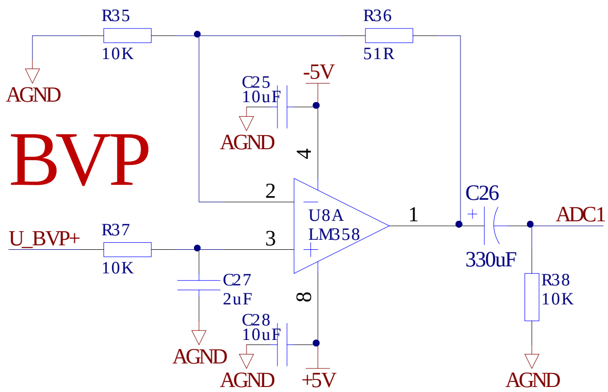


Figure 5-17. BVP signal acquisition system circuit diagram.

Specific BVP signal acquisition starts with the heart beats beating, finger-tip capillaries underwent corresponding volume changes of pulse, light with a specific wavelength shot by the optical transmitter circuit reached the photoelectrical sensor through the finger, then this process was converted into optical signals by the detected physiology quantity and converted into electrical signals by photoelectric devices. The photoemission circuit used emission wavelength within the range of circuit 600-700mm and pressure drop of generally within 1.5-2.0V. The following Figure 5-15 shows the BVP signal acquisition system circuit.

As indicated in section 4.3.4, the 4-bit LED drive through IIC bus-mastering was selected for LED program design. It specifically optimized mixed application of red/green/blue/amber (RGBA) colors. In independent luminance adjustment mode, each LED output had an individual PWM controller that was of 8-bit resolution (256 levels) and fixed frequency. It set LED at a specific luminance value and dynamic light changed according to the system program. The specific RGB LED setting following LED color values of five different corresponding rage levels was: white (R: 255 ,G: 255, B: 255); green (R: 2, G: 196, B: 125); blue (R: 37, G: 176, B: 255); yellow (R: 255, G: 252, B: 0); pink (R: 255, G: 37, B: 222); red (R: 255, G: 18, B: 0).

- On-line detection mode - when the system was connected to the upper computer, the measured physiological signals in real time were sent to the upper computer through the serials, then the current emotion was sent back to the lower computer after emotion recognition, and the corresponding LED lights were driven to show the current emotional state.
- Off-line measurement mode - when the system was not connected to the upper computer through serials, real-time physiological signals were recorded by the system and clock information and data in the U disk were read into the upper computer when convenient.

5.3.2.5 Integration and production of Creation B

The specific production process is as follows:

✓ Material selection and application

According to the test results reported in section 4.4.3, in the course of material selection, attention should be paid to the contrast of the degree of thickness and hardness. In the category of stiff and thick materials, leather was selected due to its weak light transmission whereas for soft and thin materials, silk was selected due to its strong light transmission.

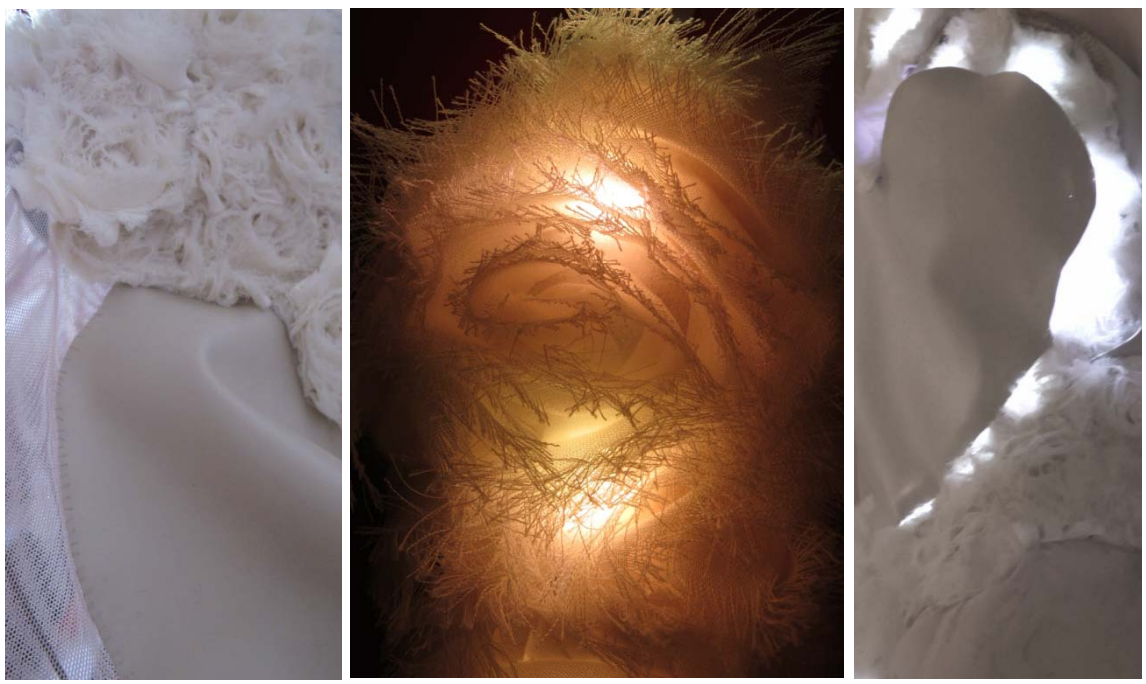


Figure 5-18. The details of material selection and application.

Contrast of thickness and thinness was purposefully designed so as to achieve the scattered light and shadow effect in the light of the inspiration while that of hardness and softness was to represent the rhythm design of fashion. In material re-design, in order to show the desired texture effect against the inspiration, silk was intensively folded with the shape being similar to petals shown in the part on inspiration, while concavity and texture smoothness on the surface formed another contrast to enhance the design rhythm. The details are shown in Figure 5-16.

✓ Arrangement of all electrical components and circuit distribution

Distribution locations of the electronic components and related circuit arrangement were determined according to design locations and practical operations. Security measures for waterproof thermal insulation were also done. The stress points of various body parts were determined from an ergonomic perspective. The placement of electronic components was

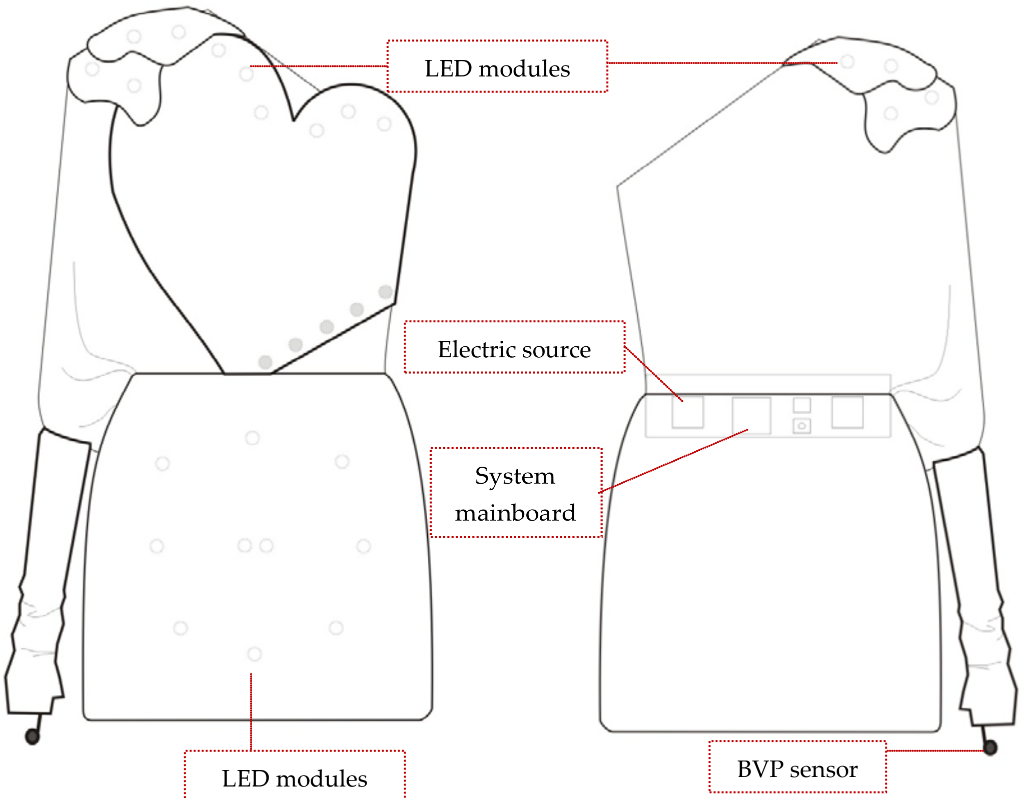


Figure 5-19. The outline of electronic components and circuit distribution of ‘Heartthrob’ Dress.

ensured not to affect the feeling of the wearer when the clothes were being worn. The sensor in Creation B was placed at the finger tip. Main board, subplate and power supply systems of the sensor system, control system and LED program system were all placed in the inner layer in the waist-hip middle-line position, as waist-hip middle line could bear the force. The inner layer was made of highly elastic materials to ensure its fitness for the body, minimize the gravity and be comfortable in wearing. In circuit arrangement, guide wires were orderly arranged and fixed along the dress structure with lines concealed. To ensure the safety of IF, waterproof and thermal and electricity insulative materials were added on the surface of all electronic components with all wires insulated.

✓ LED distribution

As per the design drawing, the LED were mainly distributed from the shoulders, stretched in curves along a heart-shaped pattern in front of the chest to the middle part of the dress and spread continuously whereby density contrast and scattered light area contrast were formed. Different distributions formed different light scattering effects which were generally divided into direct and hidden light transmittance (see Figure 5-18). The design used 36 pieces of independent RGB LED that were connected with wire.

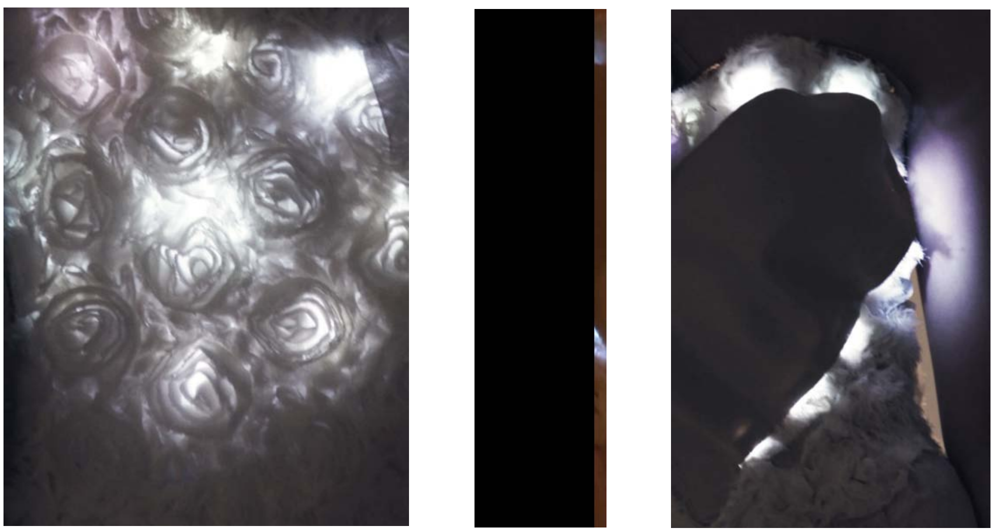


Figure 5-20. The details of LED distribution.

✓ 3D modeling manufacturing

3D Modeling was used with reference to section 4.5 Exploration with Design Aesthetics of Interactive Fashion, and combined with design concept. One of the design inspirations of the 'Heartthrob Dress' was 'heart and hand connection', and therefore, a single-sleeved, loose style was adopted, following LED distribution route to emphasize the asymmetrical effect. As part of the LED placement was in curved form, repeated combination and arrangement was needed in the sewing process to ensure the smoothness of the circuit. After the basic shape of the dress was formed, detailed processing and handling were performed so that the whole 'Heartthrob Dress' reached the anticipated aesthetic effects of the initial design concept and inspiration. Details are shown in Figure 5-19.

Figure 5-21. The details of 'Heartthrob Dress'.

5.3.3 The creation: 'Heartthrob Dress'

Figure 5-22. 'Heartthrob Dress' before interaction.

Figure 5-23. 'Heartthrob Dress' before interaction.

Figure 5-24. 'Heartthrob Dress' in real time monitoring mode (real time heartbeat/pulse).

Figures 5-23a-d show 'Heartthrob Dress' in emotional state recognition mode.

Figure 5-25a. Heartbeat/pulse rate below 70.

Figure 5-25b. Heartbeat/pulse rate in the range of 70 to 80.

Figure 5-25c. Heartbeat/pulse rate in the range of 80 to 90.

Figure 5-25d. Heartbeat/pulse rate in the range of 90 to 100.

Figure 5-26. ‘Heartthrob Dress’ turning on via wearer’s heartbeat/pulse.

5.4 Further Test with Creation A and Creation B

Towards the end of fashion creation the 'Breathing Dress' and 'Heartthrob Dress' were already complete fashion creations in their own right. Yet, in this study, a further test was conducted after the creation so as to prepare for sustainable research and development.

The test involved inviting six volunteer subjects to wear Creation A and Creation B respectively with the aim of testing the effects of the interaction processes and emotional recognition of these two dresses. Feedback relating to the try-on of these creations such as comfort and fit was also obtained from the subjects.

Test specific operation:

Each of the subjects wore the 'Breathing Dress' and 'Heartthrob Dress' respectively and watched each of the movie extracts previously discussed (i.e., those trailers in the experiments for extracting physiological signal features discussed in section 4.3.2.) for 5 minutes. The external performance of the two IF was observed and the data were simultaneously uploaded into the computer through wiring for test and analysis.

Joy	Anger	Fear	Peace
X1	X2	X3	X4

Table 5-1. The movie materials for further test.

Test result:

- Creation A：'Breathing Dress'

The subjects were represented by A, B, C, D, E, F. Data measured by the device were recorded and were compared against the interactive display effects of the IF. ★was used to represent the compliance degree of IF interactive displayed effects with 5★being the highest. The results of the comparison of the data recorded by the device and the IF display results observed by empirical observation were shown in Table 5-2:

Subjects	X1		X2		X3		X4	
	RSP	IF display	RSP	IF display	RSP	IF display	RSP	IF display
A	18/min	★★★★★	21/min	★★★★★	24/min	★★★★★	16/min	★★★★½
B	20/min	★★★★★	22/min	★★★★½	25/min	★★★★★	18/min	★★★★★
C	16/min	★★★★½	19/min	★★★★★	22/min	★★★★½	15/min	★★★★½
D	18/min	★★★★★	20/min	★★★★★	23/min	★★★★★	16/min	★★★★
E	17/min	★★★★½	20/min	★★★★★	22/min	★★★★★	16/min	★★★★★
F	19/min	★★★★★	21/min	★★★★½	24/min	★★★★	17/min	★★★★★

Table 5-2. Test result of 'Breathing Dress'.

The data were inputted into the computer, the previous binary tree method was used to test emotion recognition rate (see Table 5-3). Taking positive emotion and negative emotion as the SVM output of initial classification, the final results of binary tree discrimination were: positive emotion (Joy-Peace) – 0.75, negative emotion (Anger-Fear) – 0.91, so good recognition effect was achieved.

Emotion states	Sample Number	Correct number	Recognition rate
Joy-Peace	6*2=12	9	0.75
Anger-Fear	6*2=12	11	0.91

Table 5-3. Recognition effect of 'Breathing Dress'.

- Creation B: 'Heartthrob Dress'

The subjects are represented by A, B, C, D, E, F. Data measured by the device were recorded and were compared against the interactive display effects of the IF. ★was used to represent the compliance degree of IF interactive displayed effects with 5★being the highest. The results of the comparison of the data recorded by the device and the IF display results observed by empirical observation are as follows:

Subjects	X1		X2		X3		X4	
	BVP	IF display	BVP	IF display	BVP	IF display	BVP	IF display
A	74/min	★★★★	84/min	★★★★½	96/min	★★★★★	70/min	★★★★
B	80/min	★★★★	88/min	★★★★	100/min	★★★★★	72/min	★★★★
C	70/min	★★★★	78/min	★★★	86/min	★★★★	69/min	★★★★★
D	75/min	★★★★	82/min	★★★★	94/min	★★★★	74/min	★★★★
E	72/min	★★★★	80/min	★★★	92/min	★★★★½	70/min	★★★★
F	78/min	★★★★½	84/min	★★★★	96/min	★★★★★	70/min	★★★★

Table 5-4. Test result of 'Heartthrob Dress'.

The data were inputted into the computer, the previous binary tree method was used to test emotion recognition rate (see below). Taking positive emotion and negative emotion as the SVM output of initial classification, the final results of binary tree discrimination were: positive emotion (Joy-Peace) - 0.67, negative emotion (Anger-Fear) - 0.75, so tolerable recognition effect was achieved.

Emotion states	Sample Number	Correct number	Recognition rate
Joy-Peace	6*2=12	8	0.67
Anger-Fear	6*2=12	9	0.75

Table 5-5. Recognition effect of 'Heartthrob Dress'.

Try-on feedback:

The six subjects were all 25-year-old females. Feedback covered IF appearance designs, IF wearing comfort, and IF interactive feeling.

✓ IF appearance design

All the six subjects had a certain level of understanding of fashion design. In general terms, all the six subjects agreed that the appearance did not reveal that the 'Breathing Dress' and 'Heartthrob Dress' were wearable electronics with built-in electronic equipment. They agreed that the two dresses had certain aesthetic merit with their appealing, softly feminine details. This echoes with the core of IF visualization described earlier, i.e., *"to erase the cold and stiff feeling brought to people by technology component of IF wearable electronics from the appearance and display the beauty of the dress itself before the IF interaction, making people believe that it is just an ordinary high fashion dress".*

✓ IF wearing comfort

The try-on premise was that all the six subjects were of well-proportioned and standard figures. After respectively trying on the 'Breathing Dress' and 'Heartthrob Dress', the six wearers said that IF was heavier, which contrasted with the visual light and soft impression of the clothing. They also opined that due to the delicacy of the IF dresses, they were more careful with them during wear. Four of them said that the inner layer of ‘Breathing Dress’ fitted their bodies very well without obvious discomfort; yet as the outer layer was made of colloid with ordinary flexibility, the dresses did not facilitate action in the same way as ordinary dresses. The other wearers said that the inner layer of the ‘Breathing Dress’ was relatively more comfortable while devices on the shoulders easily slide about with human action due to gravity. For the ‘Heartthrob Dress’, all the six subjects said that they did not feel any foreign attachments or any discomfort brought by them when the dresses were being worn, and was more portable when compared with the ‘Breathing Dress’.

✓ Feeling of interaction with IF

In the process of interacting with IF, all the six subjects said that their first feeling was that these dresses were fun to try on and they gave the wearers a pleasant surprise. The sense of surprise was due to the fact that IF interaction and lighting effects were completely different from the soft feeling when they were in ordinary mode state and relatively sharp in a scientific and technological sense when they were in interactive mode. After having familiarized themselves with IF operations, five subjects said that when they were interacting with the ‘Breathing Dress’, they had a kind of awesome feeling, especially when the dresses were generating light shadow gradients along with their breathing rhythms. When watching the four trailers of selected movies, the real-time respiration status of the subjects could be expressed via the IF, reflecting their emotional states. After adjusting their personal breathing when the ‘Breathing Dress’ returned to real-time monitoring mode, the moods of the subjects returned to stable along with their breathing. In interaction with the ‘Heartthrob Dress’, the subjects reported that IF could basically reflect their emotional states and these could also be ‘read’ by spectators. The six subjects indicated that they found clothes like these favorable, and were looking forward to further trials.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the main findings and overall conclusions of the thesis "Creation of Interactive Fashion." The research and design work combined psychology, physiology, electronics, clothing materials and creative clothing design into a whole, reflecting the diversity and complexity of IF as an emerging interdisciplinary product. Two independent systems, Theoretical Framework of Interactivity and Theoretical System of Interactive Fashion (IF) were proposed in theoretical research through extensive literature review and empirical surveys and analysis. These two theoretical systems reflect their respective values in the subsequent practical research and creations' design. In practical research, the research and design direction of IF was further determined through studies in psychology and physiology disciplines by combining feasibility assessment with theories, proposing the new concept of recognizable emotions and IF visualization. In the studies, afterwards, the system applied for recognizing basic emotions through physiological signals and the IF mode used to visualize these emotions were developed through experiments and tests on physiology, electronics, and clothing materials. Creations were designed to realize the visualized IF mode for recognizing emotions through creative works by fully applying the findings of theoretical and practical research and combining them with visualization. Ultimately the research work returned to the basic purpose of being people-oriented by testing the creations on human subjects in order to test and verify IF interactive performance effects and to obtain survey feedbacks. Finally, this chapter describes certain remaining problems and limitations and makes recommendations for future research work.

6.2 Conclusion

This research proposes and establishes a specific theoretical framework of interactivity and a theoretical system of IF peculiar to Interactive Fashion through which valuable referential theoretical systems for future research are provided and future settings of IF mode are facilitated. On the other hand, the system applied for recognizing basic emotions through physiological signals in IF and the IF mode (capable of transmitting it visually) were developed through interdisciplinary research on psychology, physiology, electronics and clothing materials, etc. Finally, the purpose of this study and the design concepts are presented through creative fashion design and production. IF performance was further verified and the related feedback data was acquired through try-on tests on the dresses, based on the people-oriented concept and the purpose of sustainable research.

6.2.1 Theoretical framework of Interactivity

In the theoretical research in Chapter 3, a theoretical framework of Interactivity is proposed and established after an extensive literature review that included Interactivity in Art, Interactivity in Design, and study and analysis of real cases of Interactivity in installations, Interactivity in products and Interactivity in architectural works, though the specific cases cited in Literature Review in Chapter 2 are by no means exhaustive. The course of establishment included analyzing, categorizing and summarizing the basic process of interactivity as well as the relations and levels of interactivity. The practicality of the theoretical construct was validated with information support through a series of experiments for representative feasibility tests in various disciplines. With their framework cross-examined and expounded, a generic theoretical framework based on previous work was constructed and put forth as final.

6.2.1.1 The basic process of Interactivity

The basic elements of the principal component of interactivity were identified in the basic interaction process. They include inputs, sensors, processors, actuators and outputs. The basic forms of these elements are further summarized. An overall understanding of the basic process and content of interaction was acquired. Respective roles of these elements in the course of interaction as well as their causal effects were identified. This has laid a foundation of reference for understanding the many complex interaction processes of IF and design.

6.2.1.2 The relations and levels of Interactivity

The principal subject of interactivity is Interactive Artifact. When an Interactive Artifact interacts with humans or the external world, it involves an interactive relation and the level of interaction. Thus, a summary of interactive relations and levels of interactions among humans, Interactive Artifacts and the external world can further elucidate the occurrence and process of interactivity. Different relative relations correspond to different levels of interactivity. Designers can identify and select corresponding interactive relations in accordance with different design requirements of interactivity.

The theoretical framework of Interactivity serves as the reference for decoding interaction design cases. Its validation has been verified by many of the aforementioned case studies. Individual cases of interactive design were substituted into the theoretical framework of Interactivity for analysis. It also serves as reference for operation analysis.

6.2.2 Theoretical system of IF

Another important contribution of the theoretical research is the proposition and establishment of the theoretical system of IF. This system includes definition of IF (i.e., detailed definition of IF, and explanation of major differences between IF and traditional clothing) and design principles of IF (i.e., discussion and analysis of major elements and conditions of IF, discussion of the basic interaction processes, relations and levels of IF transformed from the theoretical framework of Interactivity, and further classification and analysis of the interaction process of IF in detail). The theoretical foundation served as the basic guideline for further practical design research and creative design of IF.

6.2.2.1 Definition of IF

Definition of IF constitutes the original part of the theoretical system analysis. The basic principles of interactivities remained very much the same since they were from the theoretical framework of Interactivity. Based on this, and taking the unique characteristics of fashion into consideration, Interactive Fashion has been defined as a marriage of cutting-edge technologies and novel materials. The form created by combining technologies, materials and design initiates the interaction between the wearer and non-wearers, which makes the otherwise static garment dynamic and actively expressive.

6.2.2.2 Design principle of IF

With reference to the theoretical framework of Interactivity and based on specifics and constraints of fashion, design principles applicable to interactive fashion have been established. These include identification of design requirements of specific interaction processes. Addressing the characteristics of fashion, corresponding adjustments have been made for addressing the design requirements and the key elements of interactive fashion. The sequence of sensor, IAP, actuator, devices and materials applies to interactive fashion. Specific feasible interaction processes are proposed, starting from the relations among wearers and non-wearers. Taking different possibilities into account, a selective range of designs of interaction processes are proposed.

6.2.3 Emotional recognition via physiological signal data towards IF

From 3.4 The Theoretical Basis of Emotional Recognition via Physiological Signal Data towards IF onward, research on IF started from macroscopic one into more specific one, i.e., research and design on IF emotion recognition. Psychological theories were analyzed for emotional recognition, including understanding of the basic concept and definition of emotion, classification models, an emotions model that was applied in this research, and deconstructing application values and application methods of various emotions and physiological response signals in emotion recognition. In Chapter 4 Practical Research, applied design research was conducted for Emotional Recognition via Physiological Data towards IF, based on previous theoretical research, including collection of physiological signals data of emotional reactions, extraction of physiological signals features and the emotions classification model applied in electronic systems with which the electronic system applied in the research was designed. LED was determined as the basic material for visual communication. Different visual expression methods were tested through experiments, by combining fashion materials and integrating resources from the viewpoint of fashion design to study the overall design effect of IF. In Chapter 5 Creations, the design philosophy and programs were determined in accordance with the emotional response physiological signals extracted and collected in Chapter 4 and electronic system design of emotional recognition via physiological data towards IF. Two independent IF creative concept dresses were designed, which represented two typical emotional response physiological signals, namely Creation A – 'Breathing Dress' and Creation B – 'Heartthrob Dress'. IF interactive performance effects discussed in the research were further tested. Try-on feedbacks from subjects were collected, which provide good references for future research.

6.2.3.1 Concept

Whatever the design is, the design purpose is always to be 'people-oriented'. Human needs include physical and psychological needs, and these needs are gradually shifting from simple to complex and from single to multiple. This is forcing designers to concern more about human heart and spiritual needs, besides issues that were not taken seriously before, such as mental anxiety. Despite the fact that these have been part of psychology and/or medicine, cross-disciplinary integration can draw studies on these issues closer to people's lives, adding a more human touch to the research. IF creation of the subject in the study was from this consideration and focused on studying emotional problems closely related to people, mainly for analysis of physiological responses to different emotions. Physiological signals data were used to recognize different emotions, and to create visuals to represent and communicate different emotions to people. IF creations should fully interpret the perceptual aspects of fashion design *per se*. On the one hand, technology should be used for achieving the objectives and functionalities while on the other hand, attention should also be paid to aesthetic aspects. A healthy attitude towards life is the theme conveyed through the innovation in this research, shifting the attention from the external material world to the inner world. From caring for and connecting with our bodies, to listening to heart, feeling our own breath to be aware of our emotions, and thus forming a virtuous cycle of interactions between our physiology and psychology.

6.2.3.2 Electronic design application for IF

Electronics applications included 1) collection of physiological signals data of emotional reactions; 2) physiological signals feature extraction for emotions classification; and 3) electronic system design for IF.

1) Physiological signal data for two typical emotional reactions, i.e. heartbeat/pulse rate and respiration, were collected. The corresponding physiological signal data were ECG/BVP signal data and RSP signal data. Forty female and male volunteers aged between 20 and 30 were invited to watch four movie trailers, expected to evoke joy, anger, fear and peace emotions. Special equipment was used to record their physiological signals under the 4 basic emotional states (i.e., joy, anger, fear and peace).

2) Models that take positive emotions (joy-peace) and negative emotions (anger-fear) as emotional category were built to be applied in the electronic system.

3) Electronic system design included hardware design, software design and LED program design. Hardware design was for input of the three physiological signals (ECG, BVP and RSP), signal conditioning, signal sampling, data transmission and data storage; using real-time clock and LED display modules. Software design was mainly for programming of induction and interaction model as well as settings of online and offline operational modes. LED program design was for LED driver settings of interactive visualization effects needed in IF design.

6.2.3.3 Creations design and production

Creations design and production work comprised mainly testing of performance effects of combinations of LED and different fashion materials, tests of different design methods applied in IF LED display, and discussion of overall aesthetics (silhouette, texture, structure and details). Creation A, named ‘Breathing Dress’, was based on ‘breath’ (RSP signal) whereas Creation B, named ‘Heartthrob Dress’, was based on ‘heartbeat/pulse rate’ (EGC/BVP signal). Design work included search for inspirational images, determination of the illustration to be used in production in the draft program, setting of targeted design rationale, determination of electronics programming and production of the electronic system, besides selection of design materials and design materials arrangement for distribution of electronic components and circuits and employment of modeling for final integration and completion of the design.

Further tests for creation A and creation B were conducted after completion of design and production. IF operating effects were tested through try-on experience and feedback of the six wearers as well as comparison of data recorded.

6.3 Recommendations

There are some unresolved issues and constraints, for example, expansion of channel used to acquire emotion recognition physiological signals, selection of new electronic components and application materials, interaction modes and systems development, wireless sensor applications, etc., which provide new directions for future IF research and design.

6.3.1 Limitations

Limitations of this research are as follows.

1) In terms of physiological signal parameters, the physical constraint lies in limitation of channels that can be applied to fashion. In addition, sensing devices were found to be either too complicated or too expensive for the limited research budget (with the exception of sensor devices for respiration and heartbeat/pulse rate which were less difficult to purchase and modify). This affected the finesse of emotions classification and accuracy of recognition.

2) Electronic components and materials are relatively cheap and easy to obtain but they were not designed particularly for applications in fashion. Thus, some transformation was required to make them suitable for clothing. Although certain new high-tech electronic components seemed to fit fashion applications better, many of them are still underdeveloped and are expensive. Acquisition of them through limited resources also proved difficult. Thus they have not been applied yet in this study.

3) There are some issues related to relations and levels that cannot be solved at present, which made it difficult to achieve the highest level of interactive mode, i.e., communicative. These problems and limitations mainly pertain to development of the interactive system. Electronic systems need a long period of pre-set data collection and debugging experiments together with repeated demonstrations; each set of electronic

system is required to have its own application procedures and has certain requirements of time and resources. Therefore, it is difficult to achieve productivity in the development of interactive mode and system.

4) At the beginning of the study, adoption of wireless sensing technology was considered because it offers more diversified applications in interaction mode. As time went by, case studies were found to suggest that subjects would be exposed to radiation by wireless sensing equipment and special materials were needed to block the radiation. The idea of application of wireless sensing technology was finally discarded due to safety reasons.

5) In design and production of IF, other forms of performance effects, besides visual communication, could not be incorporated. As the effect of visual communication is the most obvious, and due to limitations of funds, time constraints and the scope of research, only visual communication was selected for interactive effects.

6.3.2 Further research

The questions raised by this study warrant further investigations. The research subject still has ample space for future exploration. The relevant research can be developed further in the following directions:

1) Channels used for physiological signals acquisition can be expanded and classification of emotions can be more specific for higher emotion recognition accuracy. In addition to the two typical physiological signals applied in this research, the range of recognizable emotions can be expanded significantly if measurement and acquisition of physiological signals can be extended to include the other three types of physiological signals and parameters of the five physiological signals can be comprehensively used in the emotion recognition system for improving the accuracy of recognition. Therefore, future research may further explore the other physiological signals and more detailed and systematic

emotional classification models that are applicable to emotion recognition can be established.

2) Further investigation of electronic components, materials to be applied, and electronic components for optimal fashion application. It is proposed that more sophisticated electronic components be developed specifically for IF by cooperating with some technology companies.

3) Future research should focus on development of interactive models and systems. By widening and extending the scope of research, further research can be done on system development for the highest level of interactive mode, i.e., "communicative". Interactive Fashion can not only achieve human-fashion interaction, but also fashion-fashion interactions by which people can directly communicate through clothes.

4) Since wireless sensing technology has great application value for data transmission and acquisition, future research can explore how sensing technology can be applied in direct-skin-touch clothes in a safer manner. To this end, development of materials that can both block wireless sensing radiation and are suitable for wearing is imperative.

6) Future research should design and produce IF that is both aesthetically appealing and is practical in terms of functionality. Future IF should allow people to wear it in daily life, by facilitating daily activities and providing appealing appearance with intelligent interactive features. IF of the future will allow interactivity to be brought into people's lives and is expected to make significant contributions in the contexts of art & design, culture, sociology and technology.

APPENDICES

Appendix 1 Corresponding Data of Emotion states of Markov Model

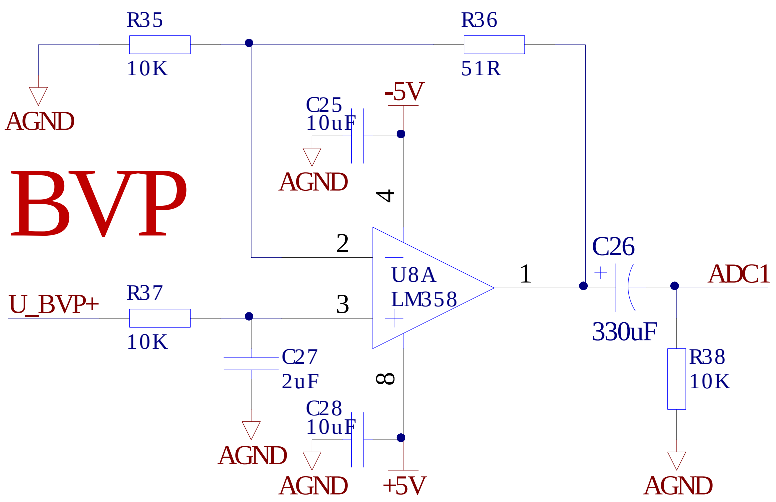
The detail data in A.1 is corresponding to Markov Model of Emotion in Figure 3-26 in 3.4.1.2.

No. of Emotion states	Emotion States
1	Peace
2	A little fear
3	A little anger
4	A little joy
5	A little fear, a little anger
6	A little anger, a little joy
7	A little joy, a little fear
8	A little fear, A little anger, a little joy
9	Fear
10	Anger
11	Joy
12	Fear, a little anger
13	Anger, a little fear
14	Fear, a little joy
15	Joy, a little anger
16	Joy, a little fear
17	Fear, a little joy
18	Fear, a little anger, a little joy
19	Anger, a little fear, a little joy
20	Joy, a little anger, a little fear
21	Fear, anger
22	Anger, joy

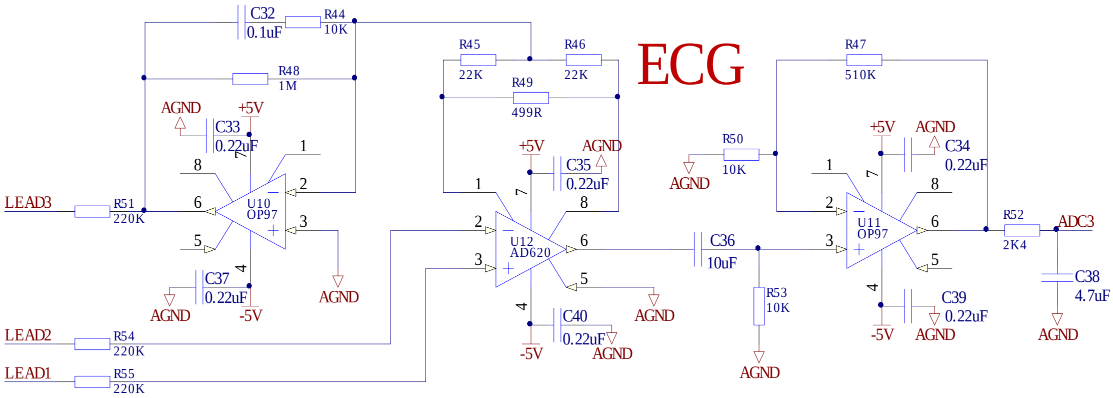
23	Fear, joy
24	Fear, anger, a little joy
25	Anger, a little joy, fear
26	Fear, joy, a little anger
27	Fear, joy, anger

Appendix 2 Circuit Diagrams of Electronic System Design for IF

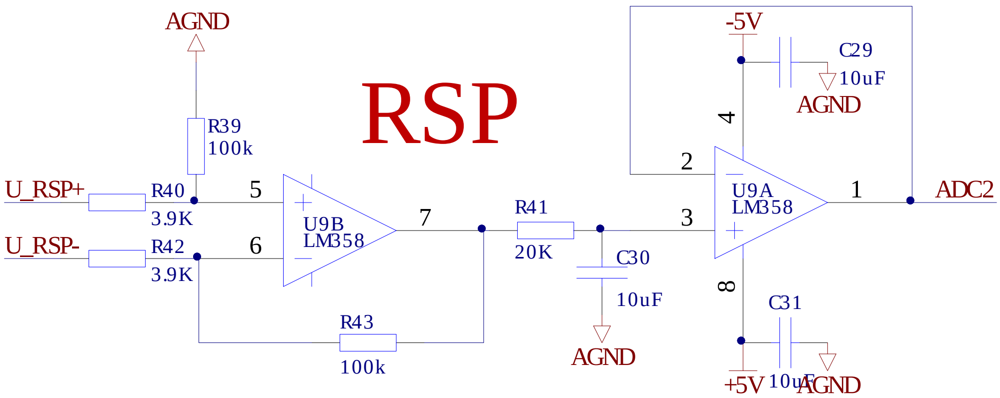
A.2.1 Circuit diagram of BVP measurement system



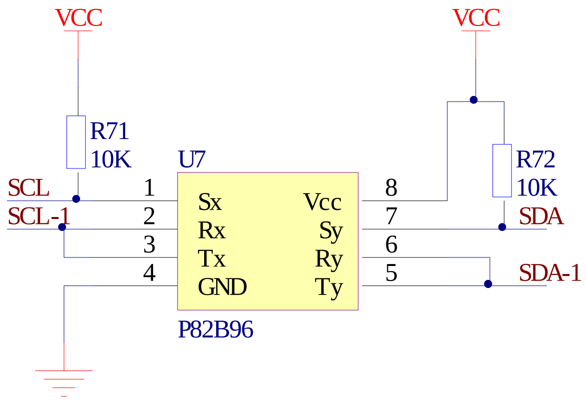
A.2.2 Circuit diagram of EGC measurement system



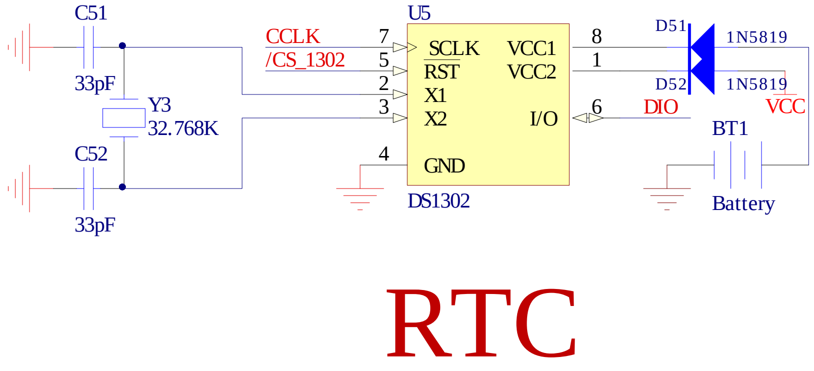
A.2.3 Circuit diagram of RSP measurement system



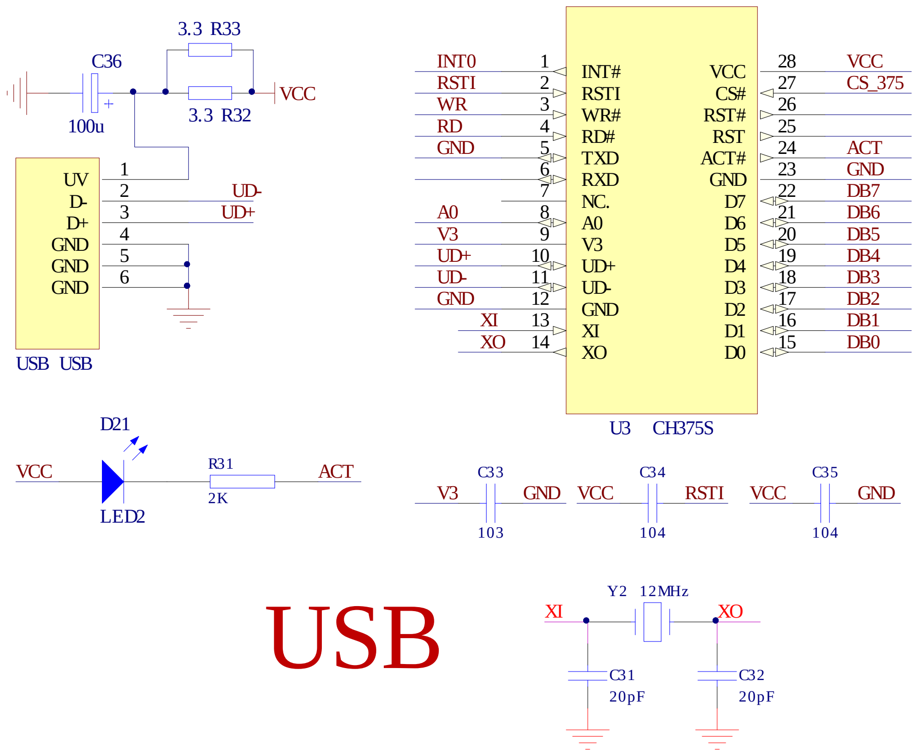
A.2.4 Circuit diagram of IIC Dual bidirectional bus buffer



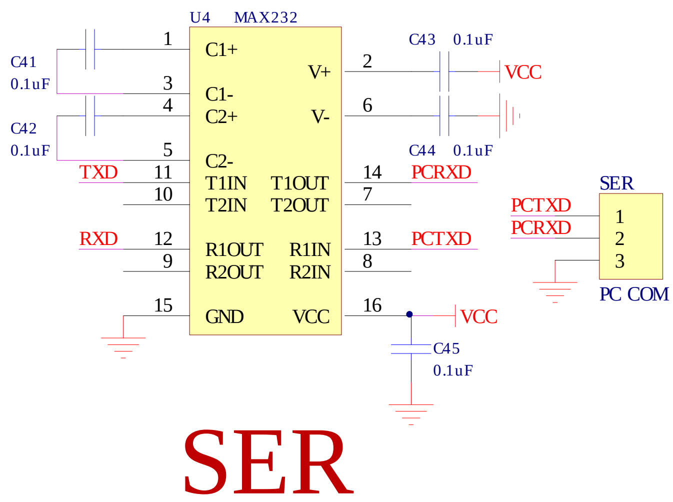
A.2.5 Circuit diagram of RTC circuit



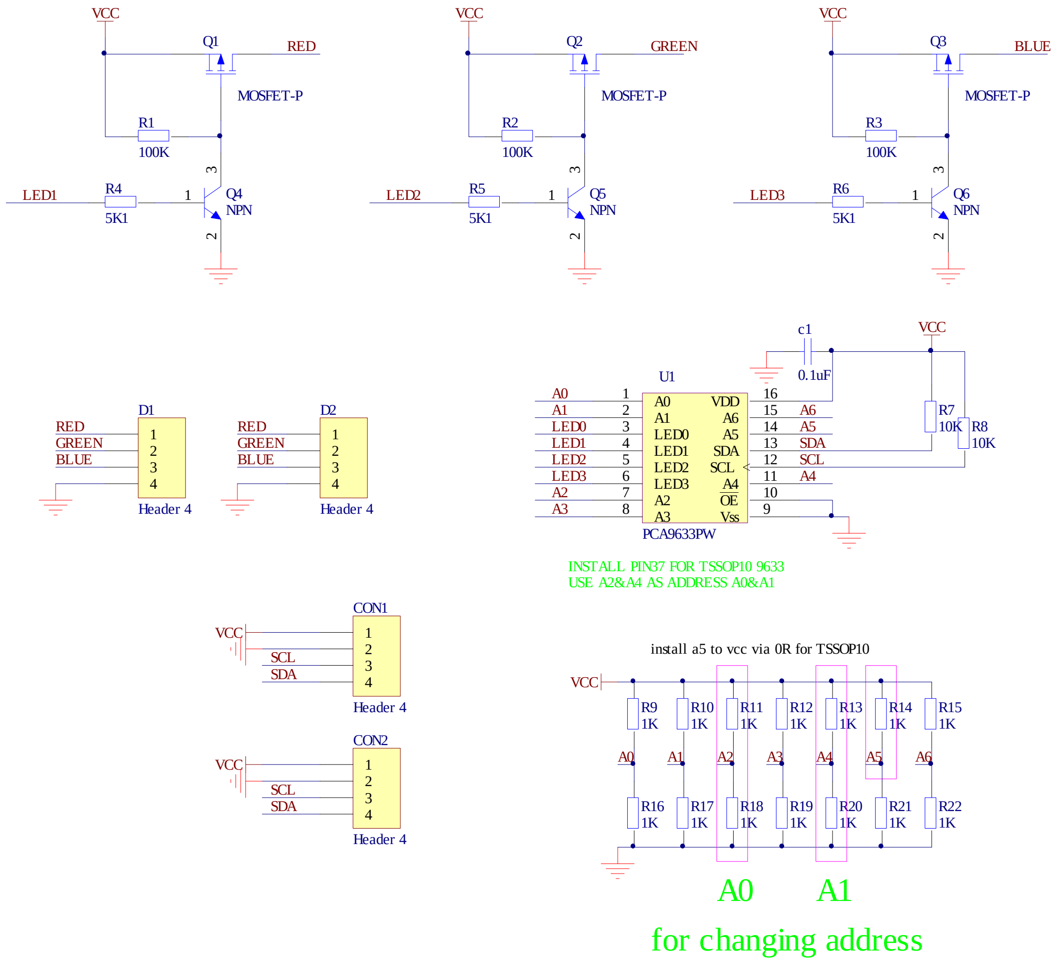
A.2.6 Circuit diagram of USB circuit



A.2.7 Circuit diagram of serial circuit



A.2.8 The control board of the LED display in detail



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