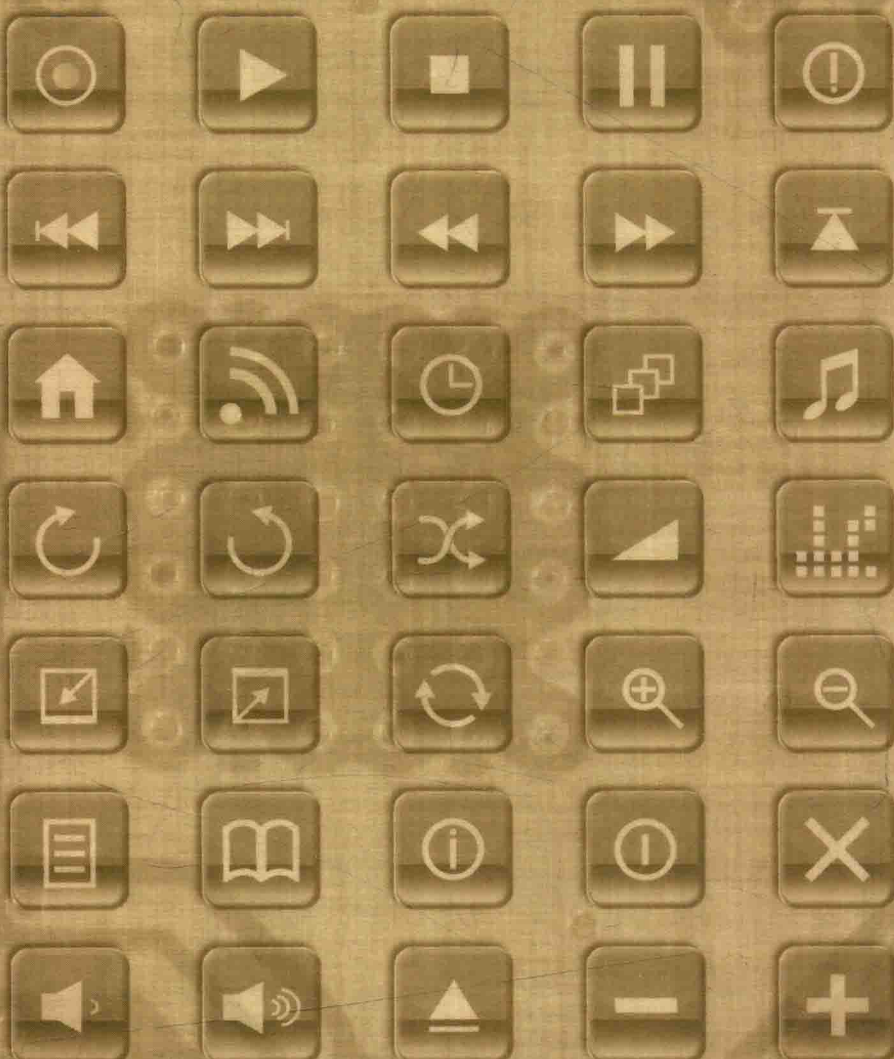
Smart Clothing

Technology and Applications



Edited by **Gilsoo Cho**

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Smart Clothing

Technology and Applications

Human Factors and Ergonomics

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Preface

The set of chapters contained here offers a unique global view for three reasons. First, they evoke the whole design cycle of smart clothes. Second, they cover applications for both the general public and professionals. Third, they dig into human aspects as well as technological aspects.

This book begins with a review and reappraisal of smart clothing by Gilsoo Cho et al., who provide a global overview by summarizing the international state of the art, identifying challenges, and evoking potential benefits of smart clothing from technological and human perspectives. Readers can thus get up to date, visualize trends, and glimpse the future.

In Chapter 2, Joohyeon Lee et al. discuss the design of technologies for smart clothing, establishing the need for methods significantly differing from traditional ones, presenting a whole theoretical design process, and providing concrete examples. Readers can relate to real cases thanks to arguments based on MP3-player jackets, photonic clothing, and bio-monitoring clothing, systems that manufacturers already commercialize though problems are by no means all solved.

In the following chapter, Yong Gu Ji and Kwangil Lee complement the discussion on design processes with a twin discussion on standardization, thus covering a critical aspect of the production and dissemination of smart clothes worldwide. They evoke trends, methods, and strategies worldwide, and detail the cases of South Korea, which is their country as well as the world leader for the production of smart clothing. Readers should value the broad scope of the information provided as well as the separate coverage of clothing and electronics.

Chapters 4 and 5 conjointly offer a view of typical enhancing components for smart clothing. Kee Sam Jeong and Sun K. Yoo present electro-textile interfaces, sensors, and actuators, and then Moo Sung Lee et al. present optical fibers. Thanks to them, the readers should understand the difficulties in choosing materials and designs that simultaneously provide targeted functions, allow a viable and elegant integration into textile and apparel, and maintain the comfort and usability of the final smart clothing in everyday life or for specific activities. As a by-product of their writing, the authors demonstrate the importance of multidisciplinary collaborations.

Reliably and efficiently exploiting combinations of components will often require particular software and hardware architectures, which will differ greatly from those existing for standard computers and multi-function cellular phones. Accordingly, Mark T. Jones and Thomas L. Martin discuss in their chapter the properties of e-textiles and propose dedicated architectures that are fault-tolerant, power-aware, and concurrently support numerous components. Although of low importance for simple cases, these aspects appear critical for complex smart clothes, and can influence their whole design.

Focusing on potential wearers, Sébastien Duval et al. explore in Chapter 7 original foundations for a global future in which smart clothes gratify human needs and match human diversity. This unique approach is theoretical and practical, clarifying trends in ubiquitous computing, testing hypotheses based on humanistic psychology in the Occident and Orient, and arguing for usefulness from birth to old age. As a result the authors propose a vision based on five key principles. Readers may consider the remarkable importance of this initiative: both meaningful starting points and clear methods are lacking to achieve projects of significant societal value, and public support remains uncertain.

In Chapter 8, Chang Gi Cho offers a deep view of shape memory materials, which possess great potential for future applications related to comfort, health, and survival, as well as aesthetics and fun, but have so far rarely been embedded into smart clothes. Readers may greatly benefit from the coverage of core aspects of shape memory materials, of a series of materials potentially very useful to design smart clothing, and of the numerous references.

In the following chapter, Daniel Ashbrook et al. sketch methods of evaluation, completing the reflections on the development cycle of smart clothes. Armed with significant first-hand experience with wearable computers, the authors provide a unique perspective. However, due to the breadth of the scope and uniqueness of their work, they could only outline the spirit in which to carry out evaluations, describe methods, and let readers be creative according to the intended wearers and smart clothes at hand. In any case, the readers should greatly benefit from this coherent approach, complementary methods, and results based on daily life as well as laboratory experiments.

Finally, Jong-Hyeok Jeon and Gilsoo Cho face the thorniest obstacle for the viability of smart clothes: the provision of energy. As a solution, they envisage creating photovoltaic textiles, textiles that absorb solar energy to transfer it as electricity to the active components. The authors first introduce the basics of solar cells, then identify milestones for the realization of photovoltaic textiles, and finally compare methods for the production of photovoltaic yarns. Readers will note that this visionary approach requires much research and development, and that success is not guaranteed. However, this first proposal may help evaluate the feasibility of the project and clarify difficulties.

I would like to thank all authors for their willingness to accept my invitation to share their pioneering efforts in this field with the readers, and for their time to prepare book chapters with their own thoughts and knowledge. Most of the authors were in the National Research Group of Technology Developments of Smart Clothing for Everyday Life sponsored by the Ministry of Knowledge Economy, Korea. I especially thank Professors Tom Martin and Mark Jones at Virginia Tech and Thad Starner at Georgia Tech for their wonderful contribution for this book. Special thanks go to Drs. Sébastien Duval and Jong-Hyeok Jeon for their participation. I am indebted to the outstanding assistance provided by all reviewers of the manuscripts. Their careful reviews and editorial suggestions improved the scientific rigor and clarity of communication in the book's chapters. I also express my gratitude to Jin Young Choi, a researcher of the smart clothing research group, for her endless devotion.

I deeply appreciate Professor Gavriel Salvendy for allowing me to edit this book in the Human Factors Book Series. Finally, I want to express my special gratitude to CRC Press for publishing this book.

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About the Editor

Dr. Gilsoo Cho has been a professor in the Department of Clothing and Textiles at Yonsei University, Seoul, Korea, since 1984. She earned her B.S. and M.S. in clothing and textiles at Seoul National University in 1978 and 1980, respectively, and her Ph.D. in clothing and textiles at Virginia Tech in 1984.

Professor Cho currently focuses her research on the development of smart textiles and clothing. She is one of the Korean pioneers in the field. She successfully mentored 20 masters students and 7 doctoral students on diverse aspects of textile and apparel science, and has published approximately 90 articles during the last 10 years. In addition, she led various research projects, notably a 5-year project for the "technological development of smart-wear for future daily life" funded by the Korean Ministry of Knowledge Economics until 2009. She has worked with scholars from several leading universities worldwide as well as partners from Korean industrial companies.

Professor Cho has been a member of the Human Factors and Ergonomics Society since 2005, and has served on the editorial board of *Fibers and Polymers* since 2000 and is currently serving as an associate editor of the journal. She has obtained 10 patents covering topics as diverse as switches in fabrics, simulations for fabric sounds, and photovoltaic yarns. She has appeared in *Marquis Who's Who* both in science and business since 2003. She was recognized as one of the top 100 scientists in 2005 by the International Biographical Center, and received an award from the Korean Federation of Science and Technology Societies in the same year.

More information about Dr. Cho is available online at:

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Contents

1 Review and Reappraisal of Smart Clothing*

Gilsoo Cho, Seungsin Lee, and Jayoung Cho

CONTENTS

* Much of the material in this chapter was published in the *International Journal of Human-Computer Interaction*, 25, 6, 582-617, Taylor & Francis, 2009.

1.1 INTRODUCTION

Clothing is an environment that we need and use every day. Clothing is special because it is personal, comfortable, close to the body, and used almost anywhere at any time (Kirstein et al. 2005). People enjoy clothing, with pleasures associated with its selection and wearing.

There is a need for an "ambient intelligence" in which intelligent devices are integrated into the everyday surroundings and provide diverse services to everyone. As our lives become more complex, people want "ambient intelligence" to be personalized, embedded, unobtrusive, and usable any time and anywhere. Clothing would be an ideal place for intelligent systems because clothing could enhance "our capabilities without requiring any conscious thought or effort" (Mann 1996). Clothing can build a very intimate form between human–machine interaction.

Smart clothing is a "smart system" capable of sensing and communicating with environmental and the wearer's conditions and stimuli. Stimuli and responses can be in electrical, thermal, mechanical, chemical, magnetic, or other forms (Tao 2001).

Smart clothing differs from wearable computing in that smart clothing emphasizes the importance of clothing while it possesses sensing and communication capabilities (Barfield et al. 2001). Wearable computers use conventional technology to connect available electronics and attach them to clothing. The functional components are still bulky and rigid portable machines and remain as non-textile materials. While constant efforts have been made toward miniaturization of electronic components for wearable electronics, true "smart clothing" requires full textile materials for all components. People prefer to wear textiles since they are more flexible, comfortable, lightweight, robust, and washable (Kirstein et al. 2005). To be a comfortable part of the clothing, it is necessary to embed electronic functions in textiles so that both electronic functionality and textile characteristics are retained. Smart clothing should be easy to maintain and use, and washable like ordinary textiles. Therefore, combining wearable technology and clothing/textile science is essential to achieve smart clothing for real wearability.

Smart clothing will provide useful services in numerous fields such as healthcare and warfare, where smart clothes can be designed to perform certain functions and support specialized activities, or sports and leisure, with more emphasis on aesthetics and convenience.

Developing smart clothes requires multidisciplinary approaches involving textile, human, and information science. Although smart clothing has progressed in various fields, advances remain in individual fields; more comprehensive reviews should associate diverse perspectives.

Here, we provide an overview of discoveries and issues in smart clothing. First, we review recent developments in technologies. Then, we consider human aspects and applications of smart clothing. Based on the current status of smart clothing, we suggest the direction to develop smart clothing and future work.

1.2 SMART CLOTHING TECHNOLOGY

In smart textiles and clothing, the extent of intelligence can be divided into *passive smart*, *active smart*, and *very smart systems* (Tao 2001). *Passive smart systems* can only sense the environment; *active smart systems* can sense and react to the stimuli from the environment; and *very smart systems*, in addition, adapt their behavior to circumstances.

A smart clothing system comprises (1) interfaces, (2) communication components, (3) data management components, (4) energy management components, and (5) integrated circuits (Tao 2005a). An interface is a medium for transacting information between the wearer and devices or the environment. A communication links components of the clothing, transferring information and energy. Data management refers to memory and data processing. Energy management relates to energy supply and storage. Integrated circuits are miniature electronic circuits built on a semiconductor substrate.

1.2.1 Interface Technologies

Input and output interfaces transfer information between the wearer and devices or the environment.

1.2.1.1 Input Interfaces

Buttons and keyboards are used as input interfaces and are relatively simple and easy to learn and implement in clothes (Tao 2005a). For complex tasks, more powerful input interfaces, such as speech recognition, are needed. Sensors can monitor the context, e.g., the wearer's physiological state or location. Much effort focuses on developing textile-based interfaces for smart clothing.

1.2.1.1.1 Textile-Based Buttons and Keyboards

Conductivity in textiles is essential to smart clothing since electrical conductivity provides pathways to carry information or energy for various functions (Lam Po Tang and Stylios 2006). Conductivity in textiles can be imparted at various textile stages. Conductive polymers, fibers, yarns, fabrics, embroidery, and finishing are all vital to construct smart clothes.

Textile-based buttons and keyboards are developed based on various mechanisms. The SOFTswitch (http://www.softswitch.co.uk) is an example of pressure-sensitive textile material. It consists of conductive fabrics with a thin layer of elasto-resistive composite, called a "quantum tunneling composite." The composite is an isolator that turns into a metal-like conductor when compressed, transforming mechanical pressure into electrical signals. This "touch-sensitive" material can serve as a switch or pressure sensor.

Sensory Fabric (Swallow and Thompson 2001) consists of two conductive fabric layers separated by a meshed non-conductive layer. When the material is pressed, the two conductive layers touch through the holes in the non-conductive mesh. This pressure-sensitive fabric can serve as a switch, soft keypad, and pressure sensor.

Another system uses a multi-layer structure to form a resistive touchpad. ElekTex is a laminate of five fabric layers, in which the outer and central layers are conductive but separated by insulating layers (http://www.eleksen.com). When touched, the layers are compressed and form an electronic circuit that generates positional values (X and Y) with a low-resolution pressure measurement (Z).

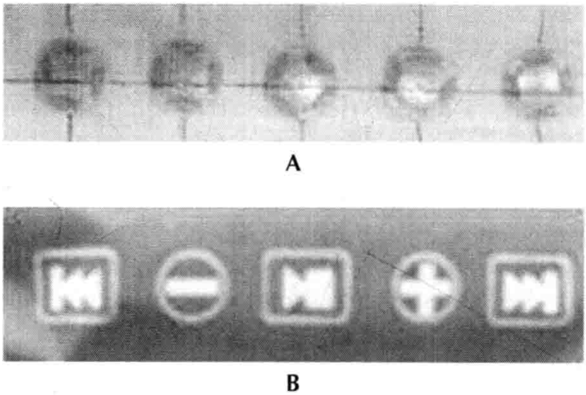

FIGURE 1.1 Switch fabric and textile-based keypad. (A) Switch fabric. (B) Textile-based keypad.

A textile-based keypad developed at the Smart Wear Research Center, Yonsei University (Figure 1.1), was fabricated using a "switch fabric." Stainless steel yarns are used as warp and filling with other types of yarn and a metal dome switch is inserted. The "switch fabric" works by contact between the conductive warp and filling yarns and the metal dome switch when compressed.

1.2.1.1.2 Textile-Based Body-Monitoring Sensors and Electrodes

Sensors measure and monitor physiological or environmental data and can act as input interfaces. Fabric-based sensors and electrodes have been developed from conductive fabrics and fiber optics.

1.2.1.1.2.1 Physiological Information Textile sensors serve to record electrocardiograms (ECGs), respiration rates, heart rates, etc. Conventional sensors often cause problems due to their physical structure or functional requirements. For example, they may cause skin irritation either due to the adhesive or gel of conventional ECG electrodes (Catrysse et al. 2004). Textile sensors are developed to overcome these inconveniences.

Van Langenhove and Hertleer (2004) developed textile electrodes for ECG and heart rate measurements. The so-called "Textrodes" are made of stainless steel fibers and have a knitted structure, in direct contact with the skin. They were incorporated into a belt for the thorax. The textile electrodes provide accurate signals as compared with conventional electrodes, despite additional noise. This technology can help monitor patients in clinical conditions and healthcare, athletes during physical activities, professionals in extreme environmental conditions, etc.

The Smart Wear Research Center, Yonsei University, developed textile-based ECG electrodes using embroidery. Stainless steel yarns were used to embroider electrodes (Figure 1.2). The embroidered electrodes were attached to knitted shirts with spandex content from 0% to 7% to examine the effect of fabric elasticity on ECG monitoring and on wearer's comfort. The performance of embroidered electrodes will be further discussed in the Section 1.3.5.

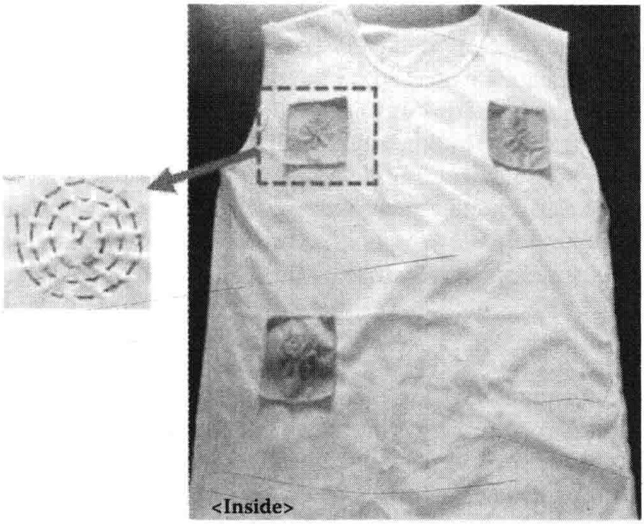

FIGURE 1.2 ECG shirt with embroidered electrodes.

In the work of Loriga et al. (2005), conductive and piezoresistive yarns were integrated in a knitted garment and used as sensors and electrodes to monitor cardiopulmonary activity. Strain fabric sensors were realized from conductive yarn as the piezoresistive domains. The fabrics exhibited piezoresistive properties in response to an external mechanical stimulus, and a voltage divider converted resistance from the fabric piezoresistive sensors into voltage. Fabric electrodes were realized with a yarn in which a stainless steel wire was coiled around a cotton-based yarn. Electrocardiogram and impedance pneumography signals were obtained from the fabric sensors and electrodes.

Catrysse et al. (2004) developed the "Respibelt," a textile sensor for measuring respiration. Made of a stainless steel yarn and knitted in a Lycra®-containing belt, it provided an adjustable stretch. The Respibelt was worn around the abdomen or thorax, and changes in circumference and length due to breathing were measured, from changes in resistance and inductance; similarly, thoracic changes in perimeter and cross-section were obtained from resistance and inductance variations.

Brady et al. (2005) integrated a foam-based pressure sensor into a garment to monitor the wearer's respiration rate. The sensor was fabricated by coating polyurethane foam with a conducting polymer, polypyrrole (PPy). The conducting polymer-coated foams were soft, compressible, and sensitive to forces from all three directions, unlike coated fabrics that work in two dimensions. The foam sensors measure chest expansion based on the compression of the foam structure between the body and the garment, whereas the conductive fabric sensors, described earlier, measure respiration rate based on the expansion and contraction of the rib cage from the stretch of the sensor.

In recent years, fiber optic technologies have attracted much attention because they offer both sensing and signal transmission. Fiber Bragg-grating (FBG) sensors are fabricated by modulating the refractive index of the core in a single-mode optic