Part I
Introduction

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Textile biomechanical engineering

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1.1 Background

Health and disease-prevention have been and are of major concern to humans, particularly for 21st century consumers regarding their apparel products. Biological health and psychological happiness are critical indexes reflecting quality of life, in which clothing plays very important roles. Clothing is one of the most intimate objects associated with the daily life of individuals, as it covers most parts of our body most of the time. Consciously or unconsciously, our physiological/biological status and psychological/emotional feelings are closely associated with the clothing we wear. A significant proportion of modern consumers understand the importance of clothing and they demand apparel products with higher added values in terms of functional performance to satisfy various aspects of their biological and psychological needs in communication, protection, healthcare, medicine and sensory comfort during wear. Naturally, engineering apparel products for biological and psychological health has become an integrated part of the concept of bioengineering.

What, then, is bioengineering? In February 1998, the United States National Institutes of Health organized a Symposium on bioengineering, at which a definition of bioengineering was formulated as follows: 'Bioengineering integrates physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behavior, or health. It advances fundamental concepts, creates knowledge from the molecular to the organ systems level, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health'.[1]

Angnew pointed out that bioengineering is rooted in physics, mathematics, chemistry, biology, computational sciences, and various engineering disciplines.[1] It is the application of a systematic, quantitative and integrative way of thinking about and approaching solutions of problems important in human biology, physiology, medicine, behavior and health of human populations. From this definition, it is clear that the biological problems are too complex to be solved by biologists alone: partners are needed in many disciplines, including physics, mathematics, chemistry, computer sciences, and engineering. Bioengineering integrates principles from a diversity of fields. The creativity of interdisciplinary teams results in a new basic understanding, novel products and innovative technologies. Bioengineering also crosses the boundaries of academia, science, medicine, and industry.

Considering that clothing has a significant impact on the health and prevention of diseases, and creating appropriate microclimates for living and appearances that influence the perceptions and behaviors of human beings, clothing bioengineering can be defined in a similar way: 'Clothing bioengineering integrates physical, chemical, mathematical, and computational sciences and engineering principles to design and engineer clothing for the benefits of human biology, medicine, behavior and health. It advances fundamental concepts; creates knowledge from the molecular to the body–clothing systems level; and develops innovative materials, devices, and apparel products for a healthy lifestyle fashion with functions of comfort, protection, prevention, diagnosis, and treatment of disease, and for improving health.'

Such a definition shows that clothing bioengineering is rooted in physics, mathematics, chemistry, polymer sciences, biology, computational sciences, and engineering disciplines in polymers, fibers, textiles and clothing. It is the application of a systematic, quantitative and integrative way of thinking about and approaching the solutions in problems of how clothing and textiles can be engineered to the benefits of biology, physiology, medicine, behavior and the health of human populations. From this definition, it is clear that clothing bioengineering needs knowledge and close collaborative research of experts from a diversity of fields, including physics, mathematics, chemistry, polymer science, computer sciences, biology, physiology and psychology, as well as engineering disciplines from such industries as polymer, fiber, textile and clothing. The creativity of interdisciplinary teams can result in new basic understanding, novel products and innovative technologies in a number of areas such as: (i) clothing bio-thermal engineering; (ii) clothing biomechanical engineering; (iii) clothing biosensory engineering; (iv) clothing biomedical engineering; and (v) clothing biomaterial engineering.

Clothing biomechanical engineering is defined as the application of a systematic and quantitative way of designing and engineering apparel products to meet the biomechanical needs of the human body and to maintain an appropriate pressure and stress distributions on the skin and in the tissues for the performance, health and comfort of the wearer. Clothing biomechanical engineering involves not only the design and engineering of fabrics, but also the measurement of body geometric profiles, and the design and engineering of garments to achieve the required biomechanical functions. Fundamental research to achieve the biomechanical functions involves a number of areas: (i) development of theories, data and models to describe the mechanical behaviors of fiber, yarns and fabric; (ii) development of theories, data and models to describe the geometric and biomechanical behavior of the human body; (iii) development of theories, data and models to describe the dynamic mechanical interactions between the body and garments; (iv) development of computational methods, computing visualization techniques, and engineering databases to integrate all the elements systematically; (v) design and engineering of materials and clothing to achieve desirable biomechanical functions; (vi) development of techniques to characterize the biomechanical functional performances from basic materials to final apparel products.

1.2 History of clothing biomechanical engineering design

Engineering design is an iterative decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective.[2] It is the link between scientific discoveries and commercial applications by applying mathematics and science to research and to develop economical solutions to practical technical problems. Engineering design has been successfully applied in a number of engineering areas such as machine manufacturing, civil engineering, and bridge construction. In 1986, the concept of sensory-engineering (Kansei-engineering) was developed by the Mazda Company in Japan as a development of human factors. Sensory means the psychological feeling or image of a product, and sensory engineering refers to the quantitative translation of consumers' psychological feeling about a product into perceptual design elements. This technique involves determining which sensory attributes elicit particular objective responses from people, and then designing a product using the attributes that elicit the desired responses. Sensory engineering has been applied with great success in the automotive industry, the Mazda Miata (MX-5) being a notable example, and is being extended to other product domains including development of new fibers.[3]

Textile products have been designed by trial and error for thousands of years. However, in the last few decades, industrial and academic experts[4–9] have recognized the importance of systematic engineering design of textiles and textile processes. In 1994, Hearle[7] presented the concept of textile-product design with fabric mechanics as a design tool. He described the different approaches available to tackle fabric mechanics in a hierarchical way and developed the concept of a computer-aided total-design system based on three frameworks: a database of information on fiber and fabric properties; a knowledge-based system using the pool of available expertise and historical data; and a deterministic suite of programs in structural mechanics. In the 1990s, Matsuo and Suresh[8] proposed the concept of fiber-assembly-structure engineering (FASE) for total material design. Total material design refers to the design of a textile product starting from the conceptual design and going up to the devising of the manufacturing method. The design has three stages: (i) aesthetic-effect or functional design; (ii) basic structure design; (iii) basic manufacturing design.

The close relationship between garment design and fabric selection means that fabric representation and design is a fundamental part of any clothing engineering design system. Fabric is a complex media to model, owing to its complicated microstructure. In the past two decades, cloth modeling has drawn wide attention both from the textile engineering and the computer graphics communities. The textile engineering approach concentrated on the relationship between fabric structure and measurement data. In the 1990s, a series of papers by Dastor *et al.*[4,10,11] presented the computer-assisted structural design of industrial woven fabric, which illustrated the possibility of creating a CAD environment to aid structural design and evaluation of industrial fabric economically. The goal is the engineering design of the ideal quality of suiting on the basis of fiber science, textile mechanics and the objective measurement technology developed. Today, there are numerous existing design programs with various software tools and a wide choice of design functions. For example, Lectra[12] and NedGraphic[13] offer the textile industry a range of CAD/CAM software packages to meet the different requirements of various woven and knitted fabrics, printed fabrics and garment design. However, in such software, the focus is the image effects rather than the geometrical and mechanical models of fabrics and garments. Many existing apparel CAD systems provide assistance in pattern design, grading, marker making and cutting processes. Most of the systems work only two-dimensionally, and the materials' mechanical behavior is not taken into account.[14]

While the textile engineering approach offers precise details of modeling cloth at a microscopic level,[15] the computer graphics approach treats fabric as a deformable object, to develop visually-realistic cloth deformation and animation. Clothing modeling and garment simulation has grown from basic shape modeling to the modeling of cloth complex physics and behaviors. A trend of employing a multidisciplinary approach has started, the two communities having begun to combine their expertise to come up with solutions that can satisfy both of them. With their efforts, 2D apparel CAD systems are extending to 3D. A 3D apparel CAD system often incorporates a suitable fabric model, and enables the designer to assess how a particular type of fabric would interact with the 3D body form. The fabric model may include links to objective data and surface visualization techniques which allow a fabric design or structure to be superimposed on the garment. Rodel *et al.*[14] pointed out that an excellent CAD system for the clothing industry should comprise three modules: a fabric library relating easy-to-determine fabric mechanical properties; a 3D model for the human body, which can be adapted for people of different sizes; and routines to construct garments from 2D patterns of specific fabrics on the human body with use of the fabric library. A common approach to constructing a garment is to accept 2D pattern shapes from a conventional CAD system, assemble them into a garment and drape or fit it onto a body form for further assessment and adjustment.

Early in 1992, Okabe *et al.*[16] presented details of a 3D CAD system with an energy-based fabric modeler incorporated. They showed examples of simulated garments fitted on a mannequin. The Asahi[17] apparel CAD 3D-PDS system, released in 1995, was also a 3D system that allowed designers to model patterns incorporating a fabric stiffness parameter. Both these systems accept the mechanical properties of fabrics. More recently, Kang and King[18,19] presented details of their 3D apparel system including flat-garment pattern generation, resizable human body modeling and garment-drape shape prediction. There was no evidence that actual mechanical parameters of fabric were used. The computer graphic community seems to be more advanced in 3D clothing modeling. There are many virtual fashion systems developed by different research teams from the computer graphics area, such as the *Virtual try on* system from the Miralab team (Geneva), *DressingSim* from Digital Fashion Ltd (Japan), and 'MayaCloth' from Maya, Spain. Most of these systems focus on generating cloth-like simulation and quick response and animation; accurate interpretation of mechanical properties and real-time performance are of secondary importance.

Although a 3D human body model is essential in all 3D apparel CAD systems, it is often assumed to be rigid, and acts as a geometrical constraint for the garment to drape or closely fit on it. The body deformation due to contact with the garment is rarely taken into account. Modern consumers demand clothing products with superior multi-functional and comfort performance to satisfy their physiological and psychological needs. Garment mechanical comfort such as pressure comfort has been identified as one of the important attributes. For example, Denton[20] pointed out that the discomfort level of clothing pressure was found to be between 20 and 40 g/cm^2, depending on the individual and the part of the body concerned, which is similar to the blood pressure in the capillary blood vessels near the skin surface. Tight-fit sportswear is reported to provide the body with suitable support and compression to accelerate blood circulation, hence improving sports performance.[18] However, the compression exerted on the human body by some medical clothing, such as pressure garments and compression stockings, has been utilized as a kind of physical therapy in clinical practice for burn rehabilitation[21] and various venous disorders.[22] The biomechanical interaction between the human body and clothing is complicated, involving many aspects. Therefore, engineering design of clothing mechanical performance demands a different kind of logical structure to that of a textile product. An important difference is that human factors (physiological and psychological) have to be accounted for in the engineering design of clothing mechanical performance, because the human is the master in presenting clothing's aesthetic and functional effects.

However, there has not been any CAD system developed for the engineering design of clothing mechanical performance, especially for 3D simulation of the mechanical interaction of the deformable human body and clothing, and sensory evaluation of clothing mechanical comfort. There are not many studies available to express a design methodology and a design process for the engineering design of clothing mechanical performance. Li and Zhang[23] presented a mechanical sensory engineering design system for textile and apparel products, which was developed based on a consideration of human factors. The system had three functional models, namely design, analysis and evaluation. The fundamental work to achieve the system functions was detailed, including the development of mechanical models, development of an engineering database and investigation of psychophysical relationships between mechanical stimulation and comfort perception. The application of the system was illustrated through an example on the design of jeans for mechanical sensory performance. However, there is much room for improvement in this system. Biomechanical engineering design of clothing products is still at the development stage.

1.3 Biomechanical engineering design for fashion products

1.3.1 Clothing design based on human factors

The study of people as a component of an engineering system is called human factors engineering. Human factors engineering is an interdisciplinary science for fitting the product to the person rather than fitting the person to the product, involving specifying design with the requirements of people as the starting point and as the main criterion for effectiveness.[24] It includes taking knowledge from anatomy, anthropometry (the science of dimensions of humans), applied psychology, biomechanics, bioengineering and physiology.

In the concept of mechanical sensory engineering design of clothing performance, human factors are concerned in two design processes: fashion design and clothing materials design, to achieve the desired clothing aesthetic and functional effects. The human factors are mainly concerned with five aspects: (i) Geometry (such as the body size and the shape); (ii) biomechanics of the human body (such as the deformation of the muscles, skin and soft tissue at different body parts); (iii) physiology (formulating sensory signals from the interactions of the body with the clothing and surrounding environments); (iv) neurophysiology; and (v) psychology (subjective perception of sensory sensation from the neurophysiological sensory signals and leading to formulated subjective overall perception and preferences). The four factors of geometry, biomechanics, physiology and neurophysiology must be considered in pattern design and material design, and the psychological factor must be taken into account in designing aesthetic effects of clothing.

Sensory engineering design of clothing mechanical performance should be based on quantitative investigations of the relationship between clothing mechanical performance and human sensory (physiological and psychological) factors. There are three fundamental investigations required to achieve the concept. The first is the quantitative translation of consumers' psychological feelings about a product into perceptual design elements that will be important attributes in the evaluation of fashion and material design. The second is the investigation of the dynamic mechanism involved in the contact interface between the human body and clothing, which bridges the relationship between human biomechanics and fashion design. The third is deduction of the clothing mechanical characteristics from the dynamic analysis, such as its deformation magnitude, stretch-recovery properties and rheological behavior during wear. These physical and mechanical characteristics of clothing materials are the basic information required for the engineering design of clothing materials.

1.3.2 Computer aiding the iterative decision-making process

Clothing design means creating new clothing by enhancing existing designs or by altering existing ones to perform new functions. The clothing design task consists of selecting the style, color and materials to meet specified functional requirements for the clothing. The conventional procedure of designing clothing without CAD technology is largely based on the experience and intuition of the designer, which has several disadvantages. Firstly, much reliance is placed upon individual designers but not on the knowledge-based design model. It is difficult to require a designer to communicate with interdisciplinary professionals to achieve the developed concept, and the training of new design 'apprentices' is a lengthy, tedious, and costly process. Secondly, it is difficult to achieve an iterative decision-making process in a short design time. Thirdly, the designer does not have the means to make a parametric analysis of the clothing mechanical performance before it is produced. Finally, it is difficult to maintain a consistently updated information system involving multiple sets of data at several locations within an organization.

A CAD system should overcome these disadvantages by the development of fundamental frameworks. It requires the development of knowledge-based design procedures to guide the user in designing clothing mechanical performance based on human sensory factors. The design starts with a product specification to identify a type of garments (e.g. jeans or bra), followed by selection of garment style and human body parameters from the human factor database and the product database. From the input parameters of the human body and the garment, the deformation characteristics of clothing should be identified, based on mechanical analysis of the dynamic contact between the human body and the garment, which will govern the next steps of selecting fabric structure and selecting mechanical properties of the fiber–yarn–fabric. The selection is a revision of design achieved by searching or reworking some previous fabric structure that reasonably approximates to the current design requirements. Next comes a mechanical model of the body–garment, allowing a numerical simulation and analysis of the mechanical performance of garment and body. The iterative procedure has to be done before the garment is produced, if the design does not satisfy through the simulation and evaluation steps. The iterative design cycle will be shortened through the CAD environment, which is supported by four engineering databases and based on a number of fundamental researches. Through the design process in the CAD system, a sample is manufactured for a wear trial. This aims to further modify the design according to subjective evaluation of the garment before formal production.

1.3.3 Analysis based on 3D virtual prototypes

The design phase determines feasible style and materials parameters; the analysis phase is used to calculate and visualize the mechanical performance of the textile and clothing system, such as distributions of stresses and strains in the garment, the deformation of the skin and soft tissues, and the garment pressure distributions on the skin. This analysis involves computational experiments of the design to test whether it meets the desired functional criteria of clothing. To analyze clothing mechanical performance based on 3D virtual prototypes requires the development of 3D mechanical models of clothing and human body that can simulate the mechanical interactions between them in different wear situations. The saying of 'A picture is worth a thousand words' is still true. Visualization of the 3D prototypes undeformed or deformed, and mechanical parameters, such as various strains, stresses and pressure, can give the designer immediate feedback on design decisions. Based on the visible simulation results, various functional analyses can be carried out. For some special garment items, biomechanical prediction can be obtained.

1.3.4 Sensory evaluation

During wear, clothing comes into contact with the skin at most parts of the body. Li[25] pointed out that the contact has three features: (i) large contacting areas with varying sensitivity; (ii) changing physiological parameters of the body (such as skin temperature, sweating rate, and humidity at the skin surface); (iii) a moving body that induces new mechanical stimuli from the contact between the body parts and clothing. The mechanical stimuli in turn induce responses from various sensory receptors and formulate various perceptions, such as touch, pressure, prickle, itch and inflammation, which affect the mechanical comfort of the wearer. The study of the psychophysical process of perception on clothing mechanical behavior makes it possible to predict and evaluate mechanical sensory comfort of clothing from the mechanical properties and structural features of fibers, yarns and fabrics, as well as garments.

Mechanical comfort should be one of the criteria to decide which design is optimal among several alternatives in the design process. The designer can judge whether the product meets the comfort requirements by comparing the predictions with desirable values, such as desirable pressure distributions and psychological perceptions of comfort pressure. Therefore, in addition to the design and the analysis functions, the system should provide the function of sensory evaluation of mechanical comfort.

Clothing comfort is very subjective. Evaluation of pressure comfort must combine the predicted pressure and the sensation index from a large volume of experiments involving wear trials. It needs much work on psychological evaluation of garment pressure, from which a series of psychophysical models will be developed based on the investigation of the relationship between objective stimuli and psychological perceptions and the investigation of the relationship between the predictions and the objective measurements. For medical clothing items, there are often criteria of specific physical parameters to be met. The evaluation of medical effects is very complicated, and requires more cooperation with clinical practice in a long-term project.

1.4 Fundamental frameworks in clothing biomechanical engineering

To develop Clothing Biomechanical Engineering Design (CBED) systems with the required functions, a series of fundamental developments need to be made by integrating science, engineering and information technologies.

The research involves a number of aspects: material modeling of textile materials of different level (fiber–yarn–fabric); mechanical modeling for the contact system of the human body and clothing; a clothing engineering database; and investigation of the psychophysical relationship between mechanical stimulation and psychological comfort perception.

1.4.1 Textile material modeling

Clothing is made of fabric, which is a flexible material that behaves with complicated deformation. Due to the complicated deformation of fabric and different pattern assemblies, garments show aesthetic appearance of infinite variations. Since fabric is a complicated structure, hierarchically built on yarns and fibers, the investigation of textiles' micro-mechanics is a stratagem whose objective is to achieve the engineering design of clothing performance from fundamental parameters of fiber–yarn–fabric structures. Models of different levels in the hierarchical structure are necessary for the material engineering design. It is also important to understand the relationship between clothing mechanical performance and fabric mechanical properties in simple deformations, such as tension, shearing, bending and compression, because these fabric properties are the basic parameters used in mechanical models of clothing.

1.4.2 Contact model between human body and garment

Clothing mechanical behavior is related to both fabric mechanical properties and the space allowance between the body and the garment during body movement. According to the degree of space allowance, garments can be classified into three types: (i) foundation garments, in which the garment area is less than the body area; (ii) perfect fitting garments, where the garment area is equal to the body area; (iii) loose garments, where the garment area is larger than the body area. Foundation garments are designed to apply a certain level of pressure on the appropriate body part when the body is both active and at rest. Perfect fitting garments have a figure-shaping function but are not designed to apply pressure on the body. Because the body movement can reduce the space allowance, loose garments may also exert pressure on the body in the contact areas. Therefore, the development of 3D geometrical models of human bodies and garments is fundamental for numerical analysis and visualization of clothing mechanical performance.

Generally, clothing behaves mechanically in a non-linear way and is subject to multi-directional stress/strain components. In approaching the complex clothing mechanics, it is usually assumed that the clothing material is a continuum of plate (planar when unstrained), or shell (naturally curved), or membrane (perfectly flexible plate or shell). This is due to the fact that many studies mainly focused on its macroscopic mechanical behavior that occurs under an external force or prescribed curvatures from a human body.

The mechanical interaction between human body and garment varies significantly for different wearing situations, depending on four factors: (i) garment style; (ii) garment space allowance; (iii) dynamic wearing or pattern assembling processing; (iv) posture of the human body. These factors have to be approached by providing different boundary conditions in the development of contact models. The mechanical system of the contact, which is often non-linear due to the large deformation and complicated contact condition, is usually solved numerically using a finite element method and other discretized methods.

1.4.3 Visualization of the 3D prototypes

A CBED system needs to provide a virtual prototyping environment to enable the designer to visualize a garment prior to making a physical sample. As mentioned previously, geometrical models are essential for the mechanical simulation. Various 3D prototypes need to be generated, positioned properly, and discretized for the further mechanical analysis. Once the mechanical analysis has been completed, the results need to be evaluated. The 3D garment fitted to the human body needs to be visualized for assessing the garment aesthetic shape and fit. The displacements, stresses and other fundamental variables in clothing objects as well as the human body that have been calculated, need to be visualized and plotted for appraising fabric suitability and wearing comfort, and other functional analysis and evaluation. The visualization is generally done interactively utilizing the specific visualization modules for the analysis solvers used, some general graphic tools, or other specifically developed pre- and post-processors.

1.4.4 Clothing engineering database

To support the design, analysis and evaluation phases in a systematic design process with various types of information, it is necessary to develop an engineering database. An engineering database has several important differences from an administrative database or a business database. Firstly, engineering design is an iterative-decision process with analysis and synthesis based on knowledge of basic sciences, mathematics, and engineering sciences. Secondly, engineering design needs a dynamic database that involves two kinds of information: the design environment (rules, methods, standard elements, etc.) and data that are not known previously but defined during the design process. The volume of information increases with the progress of a design. Thirdly, engineering design deals with a number of data types (text, numbers, equations, diagrams, graphical, photographic images, etc.).

An important characteristic that must be considered in the development of a clothing engineering database is that the clothing design process communicates frequently with the information from the hierarchical construction of a fiber–yarn–fabric–garment and a 3D human body. The structural geometry of textiles is central to all aspects of the computer-aided design and prediction, which should be presented to the designer during the design process. Therefore, the clothing engineering database should support user-friendly program packages to input, store and display the information of fiber–yarn–fabric–garment quickly and effectively in time and space.

1.4.5 Investigation of psychophysical relationship between stimulation and perception

To visualize the sensory perception in the CAD environment, a series of psychophysical experiments have to be carried out to study mechanical comfort of the garment in different wear situations by conducting mechanical sensory comfort perception trials and objective measurement of dynamic pressure distribution. Further, psychophysical models of mechanical comfort have to be developed in different wearing situations, by using statistical methods, neural networks, etc.

1.5 Clothing biomechanical engineering design system: an example

Advances in technology, computer performance and cloth simulation research make the development of a CBED system possible. Now that cloth simulation has been addressed widely from 1D fiber level to 3D garment level, and the physical testing techniques of textiles have been advanced, the challenge is then to integrate these modeling and information techniques logically and effectively and build an interactive and creative system for the engineering design.

The system conceived and developed in the Institute of Textile and Clothing, Polytechnic University of Hong Kong, for the biomechanical engineering design for textile and clothing products is briefly outlined.[23] This system integrates clothing design process, clothing–body biomechanical models, numerical solutions, analysis and evaluation of clothing sensory mechanical performance into a CAD environment based on a collection of well-integrated software tools. There are eight working modules in the system: (i) user interface; (ii) design processing algorithms; (iii) generation of 3D geometrical primitives, realized using pre-processing software or graphic tools; (iv) definition of boundary conditions of the contact system, performed using preprocessors; (v) mechanical analyzers – can be commercial software, such as LS-DYNA (Livermore Software Technology Corporation), ANSYS (MSC.Software, USA), ABAQUS (Hibbitt, Karlsson & Sorensen Inc., USA) and specifically-developed solvers; (vi) result visualization, performed by using some post-processors; (vii) sensory evaluation; (viii) engineering database. There is also a control communication module connecting with each of the eight working modules, indicating the broad division of the information communication among the working models and the software environment of the system. Each working module accomplishes its purpose with suitable software. A key feature is the integration of relevant software components into the CBED system, because many of the software packages have been developed independently in different industries for their specific purposes, with little knowledge of mechanical engineering design of textiles.

The originality of this system is evident in four major aspects: (i) consideration of human factors (physiological and psychological) in engineering design of clothing products; (ii) simulation and visualization of clothing mechanical comfort performance before the garment is produced; (iii) integration of a range of software components into the system for computer-aided engineering design; (iv) provision of a platform with an engineering database to input, store and display information about the hierarchical mechanical properties and structural features of garments and human bodies. The system aims to provide a design methodology and a tool for fashion designers and textile scientists, engineers and product developers to design new products efficiently with consideration of mechanical performance.

1.6 Outline of this book

This book is divided into five parts. Part I is this chapter as an overall introduction. In Part II, the fundamental scientific theories, principles and models behind the mechanical sensory design technology are described. There is a hierarchical interrelation among textile products, from fiber, yarn and fabrics, to clothing. Two sets of parameters are involved – properties of the constituents and structural geometry. All of these features must be taken into account in garment product design. Micromechanics and macromechanics are the usual tools in tackling the problems of mechanical performance for textile products. Micromechanics covers predicting the fundamental constitutive relations for any textile structure in terms of the two sets of parameters mentioned above, while macromechanics is concerned with predicting the complex response of a material subject to the collection of forces imposed in practical situations. A fundamental understanding about these micro- and macromechanics in textiles is introduced. The modeling techniques are also overviewed. As the subject for clothing, the human body's geometrical and biomechanical features and sensation, and its contact problem with clothing are also introduced.

In Part III, the brief development history, structural features and mechanical properties of textile materials are described from fibers, yarns, and also the fabrics to clothing, and also the mechanical properties of the biomaterials of the human body. The parameters relevant to clothing mechanical performance are introduced and the major measurements for these properties are reviewed. These parameters will be included in the database for the design system.

In Part IV, the clothing biomechanical engineering design system is discussed, with a detailed explanation of the system construction, including integration of mechanical models, numerical solution approaches, pre- and post-processing and the database constitution.

Finally, in Part V, several practical examples of product development, such as jeans, sports bras, compression stockings, socks, shoes and aerobic sportswear, are provided to illustrate how to carry out the biomechanical engineering design.

This book is the result of the contributions from the authors and the work of other researchers on the important topics of the textile and clothing biomechanical engineering. The authors hope that the book will help interested beginners to carry out research in the area and to motivate current researchers and developers in this area towards further development and applications.

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