# An Overview on Computational Techniques in Textile Engineering

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***Abstract:*** This paper discusses a number of computational problems in textile/garment industry. These problems cover quality inspection of textile products, on-line process control and monitoring, process and material modeling and simulation, CAD for clothing and materials, and computerized management of production and supply chain. Recently, more attention has been paid to modeling and analysis of human related complex concepts such as well-being, textile comfort and marketing elements and their integration in the design of new products. The related computational techniques include classical methods such as statistics, physical law based analytical equations, classical signal and image processing and statistical pattern recognition, and intelligent techniques such as soft computing and data mining. The selection of specific computational techniques is strongly related to the nature of the problem of interest. An optimal solution to a complex textile or garment problem can be found by combining several complementary techniques in a suitable way.

***Keywords:*** computational techniques, textile, garment, intelligent techniques, complex concepts, industrial design

## 1. Introduction

Modern textile/garment industry is faced to a great number of competitive challenges such as:

- Shorter product life cycles: distributors and consumers are looking for more variety and personalization.
- Lack of flexibility in the supply chain.
- Cost reduction: retailers do not want to lose their sales margins which generate a pressure to compete for cheaper prices on products.
- Homogeneity need: the lack of integration, the heterogeneity and the lack of standards is a chronic weakness of the textile and garment industry.
- Consumers demand more comfortable textile and apparel products as casualization becomes a global trend over the decades.
- Biofunctional performance of textile devices and apparel products becomes critical area of concerns as more and more consumers pay attention to making healthy lifestyles.

Under this challenging economic pressure, there is a strong need to develop new methods in order to optimize the quality of textile products, textile design and textile management. Information technology, especially computational techniques can play an important role in this optimization [1].

Since 1950's, computational techniques have been widely applied in textile industry and garment industry for process and materials' structure modeling, simulation and control, optimization of product quality, product design, textile market forecasting. Recently, more attention has been paid to integrating some human related complex concepts into the design of new products. These concepts can be well-being, textile comfort, sustainable development and other market oriented as well as social and economic criteria. The integration of these complex concepts needs powerful computational tools capable of formalizing and analyzing uncertainty and imprecision frequently encountered in human knowledge.

The current computational techniques include classical methods such as statistics, analytical equations, classical signal and image processing (time series analysis and frequency analysis) and statistical pattern recognition, and intelligent techniques such as

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soft computing and data mining. Classical methods are essentially based on formalization of physical laws such as computations of fluid mechanics and finite elements. Basic mechanical laws have been exploited to model and simulate structures of materials and processes. Intelligent techniques are often used to deal with uncertainty and imprecision related to human knowledge on products and processes and linguistic data analysis. In practice, the selection of specific computational techniques is strongly related to the nature of the problem of interest. In general, an optimal solution to a complex textile problem can be found by properly combining several complementary techniques.

In the following sections, we discuss some typical applications of computational techniques in textile and garment sectors. More emphasis is given on the following areas:

- Automatic textile quality inspection,
- Modeling and control of textile process and fabric constitutive relations,
- Modeling and simulation of material's structures,
- Computerized management of enterprises and Supply Chain,
- Computer aided textile and garment design,
- Integration of complex concepts in textile design.

## 2. Automatic Textile Quality Inspection

Quality control is very important in textile/garment manufacturing industry. The defects in fabrics may reduce the price of a product by 45-65% [2]. Traditionally, textile quality control is performed by human evaluators mainly according to textile appearance and fabric hand. Some key physical and mechanical properties of textile materials (fibers, yarns, fabrics) are usually measured in a specialized laboratory. These normalized physical measures and the subjective human evaluations constitute a vector of features characterizing the quality of textiles. In modern textile industry, in order to increase the accuracy of quality inspection and reduce the corresponding cost, it is necessary to replace human visual and tactile evaluations by a reliable, objective and consistent quality control process for automatically detecting possible defects [3].

### 2.1 Visual Quality Inspection

A great number of automatic visual quality inspection systems have been developed for detecting defects in woven, knitted and non woven fabrics. These systems are usually composed of three parts: 1) feature extraction from fabric images, 2) relevant feature selection, and 3) textile quality classification.

The features are generally extracted from fabric images using statistical methods, frequency analysis and model based techniques [3]. As most of textile fabrics have high degree of periodicity, frequency analysis, including Fourier Transform, wavelet transform and Gabor analysis, have shown better performance in quality inspection.

Having extracted features from fabric images, we need to select a small number of the most relevant features for improving the accuracy of quality classification [4]. The techniques for relevant feature selection are mostly supervised methods, i.e. the objective of selection is to improve the classification accuracy or class label predictive accuracy of learning data samples [5]. Several well-known methods are the decision-tree method, the nearest-neighbor method, the wrapper model and the information-theoretical connectionist network model.

The last step of visual quality inspection is the classification of vectors of selected features in order to obtain different quality levels [6]. This step can be carried out using supervised methods in which a set of known samples can be used for learning classifiers and the quality of a new fabric sample can be predicted by comparing its features with those of the identified classifiers. Neural networks and fuzzy neural techniques are frequently used in the learning of classifiers [7].

Most of automatic visual quality inspections are performed using static image analysis systems for finished products. However, some of them are done with dynamic image analysis systems each equipped with a high speed camera, an online processing and a controllable transport belt for online inspecting quality of finished products and intermediate products [8].

This procedure has been successfully applied to automatic detection of fabric and yarn defects and recognition of textile seams and other quality levels.

### 2.2 Tactile Quality Inspection

The realization of fabric hand evaluation is more difficult than that of automatic visual quality inspection because there are no powerful devices like computer vision system for extracting relevant tactile information from fabrics and the subjectivity in hand evaluation is higher than that in visual evaluation. A number of mechanical devices, including KES (Kawabata Evaluation System), FAST, and UST (Universal Surface Tester), have been used to objectively characterize fabric hand quality. However, the measured mechanical parameters can not directly reflect human sensation on fabric hand and need to be interpreted with respect to normalized subjective human hand evaluation. In this situation, the characterization of the relationship between objective parameters and subjective hand evaluations becomes a key problem in tactile quality inspection.

A number of computational models have proposed to characterize this relationship. These models are based on psychological laws [9] or sensory data analysis, including factorial analysis [10], neural networks [11] and fuzzy models [12].

In general, progress in this field is rather slow due to the following difficulties : 1) there exist uncertainties and imprecision in subjective evaluation because experts often affect different linguistic descriptors and different scores to the same fabric sample; 2) the relationship between subjective and objective evaluations constitute a nonlinear complex system in which no analytical models are available.

Sensory analysis techniques have been used to reduce uncertainty and imprecision in tactile information and normalize evaluation descriptors and scores. However, the current sensory evaluation procedures are uncertain and should be improved by developing optimal and more normalized design of experiments. Soft computing, especially fuzzy logic and neural networks can be an efficient tool for formalizing sensory data and modeling the relationship between sensory data describing fabric hand and objective measured on instruments. In the modeling procedure, it is necessary to integrate experimental data, human knowledge given by experts on processes and products, as well as related physical and psychological laws in a suitable way [12]. A multi-model approach can be a good orientation leading to more relevant results of modeling.

## 3. Modeling and Control of Textile Processes

### 3.1 Modeling and Control of a Single Process

A textile process can be represented by the scheme in Figure 1, in which the parameters characterizing raw materials as well as machine settings are considered as input variables and features characterizing end product as output variables.

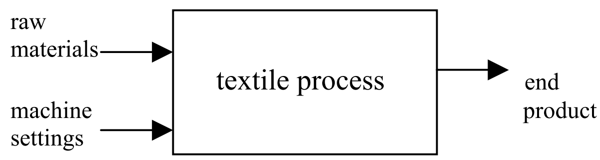


Figure 1 Representation of a textile process

For understanding the behavior of a textile process and controlling it, we need to create an efficient and accurate model. The modeling step can be done using physical or mechanical laws if these laws are available and easy to be understood. In most of cases, these laws are not available and the model has to be uniquely built from empirical data measured on the process and the product. Human knowledge obtained from operator’s experience and qualitative physical principles can also be integrated in the model as the second source of information [12].

In empirical modeling, statistical tools such as linear regression and PCA (Principal Component Analysis) are frequently used to model the relations between input and output variables. However, if these relations are too complex or there exist qualitative data in the related variables, classical tools can not lead to satisfying results and soft computing techniques can be more efficient to model these relations due to their capacity of processing uncertainty and imprecision. A fuzzy model can be built by learning fuzzy rules from measured numerical data and qualitative human knowledge. A neural network can be built from measured numerical data by learning its internal parameters. The former has good capacities of physical interpretation for users while the latter has advantages of quick learning and high precision [13]. In practice, these two techniques are often combined in a complementary way to form fuzzy-neural models [14]. Moreover, genetic algorithms are generally used to optimize internal parameters of models.

The online control can be realized using open loop or closed loop. In open loop control, we use the model built previously to find suitable input values from desired output values. In a closed loop control, the control strategy is generated at each instant according to the current process state, the desired output value and the relationship between previous output values and control values. Time effect should be considered. Different from the modeling step, learning and control generation are carried out in the same time in the control step. The most well-known control strategy for textile processes cover from classical PID method to fuzzy control and neural network control systems.

Online control has been widely applied to textile processes [15]. In particular, a quantity of original work has been done for online control of dyeing process in which concentration of dye mixtures, pH and temperature in the dyebath behave nonlinearly and interact between them. Fuzzy logic and neural network have been used in this control to simulate the decision-making of experienced experts and select optimal structures for process environments [16].

## 3.2 Modeling and Control of a Collection of Coupled Processes

A textile manufacturing system generally consists of a collection of processes coupled together. In such system, analytical models are generally not available but empirical data and some knowledge about the processes can be obtained. In [17], a hierarchical control strategy is proposed to a textile plant of warping, slashing and weaving for optimizing a global objective function, i.e. maximizing the productivity and reducing the total number of defects (see Figure 2). The control strategy is composed of fours parts: 1) modeling of individual processes, 2) integration of all process analysis for making intelligent decision of the overall control system, 3) optimization and 4) local control.

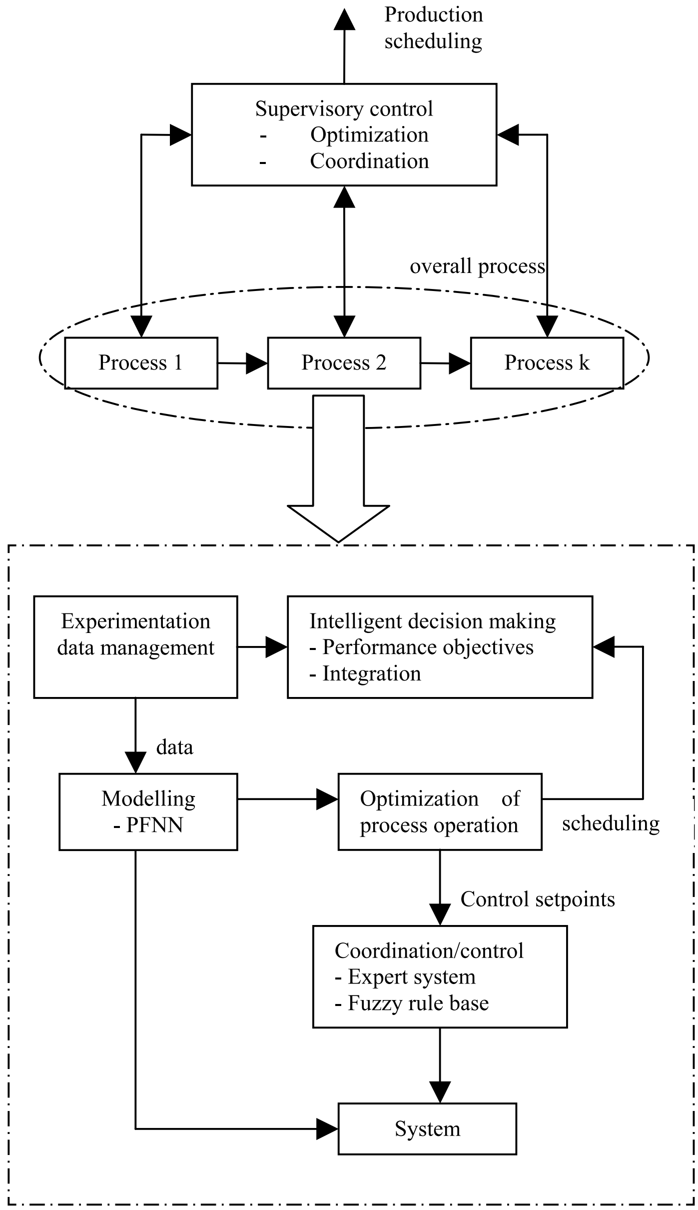


Figure 2 The hierarchical control strategy

In this strategy, a polynomial fuzzy neural network (PFNN) is used to model nonlinear dynamic processes from statistical data and operator's knowledge and to construct fuzzy objective functions. The supervisory level of the control architecture is intended to continuously improve the control setpoints depending upon feedback information from the weave room, slasher operator, and warping data. The setpoints in the slashing operation need to be optimized since the strength of the yarn that results


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from the slashing process is an important factor in how a fabric is woven in the weaving machine.

## 4. Modeling and Simulation of Material's Structure

Modeling and simulation of textile structure for predicting moisture diffusion and permeability is very important in design and manufacturing of textile materials, especially for composites with textile reinforcement. Fluid flow physics and finite elements are two classical tools in this modeling. In fluid flow physics, Darcy's law and other analytical equations have been used to compute both bulk permeability values and micropermeability values of dual scale fabrics [18]. Finite elements have also been used for discretely modeling tows (yarns) and matrix pockets and modeling the through-the-thickness diffusion behavior [19].

In practice, the performance of these models is often affected by the uncertainties existing in the structure of materials, including 1) strong interaction between composite components, 2) uncertain in material parameters, 3) complex and irregular structural geometry. As these uncertainties deal with both randomness and fuzziness, fuzzy logic and stochastic modeling have been used to formalize these uncertainties, integrate expert knowledge on materials and model the structure of textiles [20]. Another method has been proposed to model and simulate irregular pore network and geometric properties of pores using image analysis and compute the pore size distribution [21].

## 5. Computerized Management of Production and Supply Chain

### 5.1 Computerized Management of Enterprises

Computational problems in textile management mainly include: modeling and simulation of enterprise internal organization, production scheduling and control, performance evaluation for products, human resources, raw materials and suppliers, forecasting of finished product sales, etc. Defining a relevant and flexible production scheduling and control strategy is a key problem in textile production management. It comprises various production phases from fiber production to garment making. Each phase is sequential manufacturing process with multiple production units. In each unit, a number of identical or different machines work in parallel. The textile industry imposes a variety of constraints concerning the integration of the overall scheduling procedure. The scheduling problem can be considered as a mixture of flowshop and jobshop [22]. The features of "quick response" and "just in time" should be taken into account in the related planning tasks. In the well-know scheduling systems MRP-II and OPT, the combination of forward and backward scheduling has been used to solve the previous problems. In the existing production control systems, fuzzy expert systems, neural networks and neural-fuzzy approaches have been used to material flows and determine economic related goals [23].

In performance evaluation systems, multi-criteria decision making techniques have been used to select the most relevant object (product, production structure, human resource, material, …). Fuzzy techniques are suitable tools to formalize human related performance criteria and compute with linguistic criteria and goals [24].

### 5.2 Computerized Management of Supply Chain

In a textile supply chain, the manufacturers from yarn production to garment making are distributed over a large geographical area. The computational problems in this supply chain essentially deals with analysis and optimization of material flow, product flow and information flow between different manufacturers.

Transportation is a key problem in supply chain management. A collection of solutions, including composite trailer routes, tour generation and selection, and column generation methods have been proposed to solve routing decision problems for TL (full truckload) and LTL (less truckload) shipments in textile supply chain [25].

In a more general background, a supply chain network composed of SMEs (Small and Medium Enterprises) generally deals with variability and uncertainty modeling, dynamic forecasting, incorporation of economic criteria, global, multi-objective and real-time dynamic optimization, coupling optimization with simulation, definition of cost models, etc. The modeling of the textile supply chain is generally realized using a network structure in cooperation with a data mining module for forecasting demands and costs [26]. The modeling process is supported by an object-oriented approach in combination with a user-friendly graphical interface. Forecasting and cost estimation can be realized by integrating statistical tools and neuro-fuzzy models [27]. Moreover, it is necessary to identify some key performance indicators so that end-users can evaluate different alternatives. In [26], the performance evaluation is a multi-objective optimization problem and realized using a simulation based genetic algorithm.

## 6. Computer Aided Textile and Garment Design

The design of fabric structures strongly depends on the use of computer software, enabling designers to determine the shape, perform a static analysis, and produce fabric layers [28]. The structure of fabrics is very complex because of textile flexibility. Moreover, a great of design parameters should be considered in the process of textile design. It is for these reasons that textile design requires repeated analyses for successive modifications on materials.

This procedure generally deals with a great number of nonlinear models and extensive computational costs. In [28], a sensitivity analysis module and an Augmented Lagrange Multiplier based optimization module have been developed to give designers a better structural behavior understanding and determine optimal adjustment of design parameters respectively.

Computer-Aided Design techniques, especially two dimensional tools have also been widely to garment design. However, 2D CAD techniques can only provide 2D patterns, which are not directly related to wearer's fitting comfort. Moreover, the ultimate goal of garment design is to quickly produce well-fitted personalized garments for individuals. In this situation, a 3D CAD approach producing a series of virtual prototypes seems to be more adapted to garment design. A 3D CAD approach includes 1) 3D-mannequin modeling, 2) 3D-garment simulation, 3D-pattern design, and 3D/2D conversion [29].

3D-mannequin modeling is often realized from laser scanned 3D unorganized data points measured on human body. For example, in [30], the semantic feature extraction technique is firstly applied to construct the feature wireframe from human body data. Then, a continuous mesh surface is generated to interpolate the curves of feature wireframe using Greogry patches. A voxel-based algorithm is used to add more details on this surface.

3D-garment simulation is based on mechanical models or geometric models [31]. A mechanical model is built according to the mechanical properties of real cloth measured on devices such as KES and FAST measuring systems. It can effectively simulate deformable structures. In practice, a mechanical model should be accurate enough to deal with nonlinearities and deformations occurring in cloth, such as folds and wrinkles. Moreover, it strongly interacts with the corresponding wearer or the human body model. Therefore, advanced and complex computational methods are required to detect geometric contacts constraining the behavior of the cloth and integrate them into the mechanical model (collision detection and response). The finite element method is the first tool to set up mechanical garment models. It considers a cloth surface as being discretized in interpolation patches and an associated set of parameters (degrees of freedom) that give the actual shape to the interpolation surface over the element. The mechanical energy can be computed from measured properties and the deformation of the surface. Another more efficient method for building mechanical garment model is particle system. It permits to define rough models that compute highly deformable mechanical properties within a very short time.

A geometric model does not consider the mechanical properties of the cloth and then provide fast results for garment modeling. It can be realized through successive interactions with garment designers. This approach is simpler but sometimes produces results different from the behavior of the real cloth. The combination of mechanical and geometric approaches has been proved to be more efficient than any single type of models.

Virtual garment design can be realized using 3D-mannequin models and 3D-garment models. Moreover, 2D-garment patterns generated using classical methods can be modified by 3D-garment fitting simulation results [32].

# 7. Integration of Human Related Complex Concepts in Textile Design

More and more industrial companies are interested to exploit some human related complex concepts and integrate them into design of textile/garment products in order to meet personalized requirements of consumers and massive social and environmental criteria. These concepts include well-being, comfort, sustainable development, fashion style, brand, etc. Current research on mass customization is generally focused on integration of personalized technical parameters such as body measurements but never deals with personalization of these complex concepts.

In the future development of computational techniques in textile/garment industry, one important trend can be to

- formalize and analyze these complex concepts,
- develop a relevant and normalized design of experiments (questionnaire, evaluation procedure, descriptors, etc.) to collect personalized requirements of consumers on these concepts,
- set up relevant models characterizing the relationship between technical parameters of materials and processes and these concepts.

The research carried out in this field will enable to design and produce new products or adjust existing products according to evolution of personalized needs of consumers and massive social and environmental criteria. Especially, with the results obtained in this flied, mass customization and virtual prototyping can be further developed by taking into account more personalized criteria in design of virtual products.

Apart from the computational techniques presented previously, more efficient tools on semantic analysis and automatic learning are needed in order to formalize unstructured consumer data on these complex concepts and set up models from these data. More relevant solutions can be obtained by combining soft computing techniques and semantic analysis in a suitable way.

# 8. Conclusion

This paper discusses computational techniques in several typical textile/garment applications. It is not an exhaustive summary of all applications but just to provide some ideas to understand how computational techniques can be applied to solve a complex textile problem. From the previous analysis, we can see that soft computing techniques, especially fuzzy logic are efficient tools because they have better capacities of treating uncertainty and imprecision, frequently encountered in textile/garment industry.

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