Thesis Orientation and Introduction

1.1. Introduction:

Over the past few years, the author of this work has been engaged in an intensive research with multi-disciplinary research groups and worked on different projects that covered: the applications of nanotechnology in developing efficient biological and chemical protective materials, enhancing the mechanical and interfacial properties of nanocomposites, developing biocomposite materials for tissue engineering applications, and the utilization of computational methods to solve problems related to the evaluation of fibrous structures. This offered a great chance for an experience in three main research fields that are shown in Figure 1 and cover the study of structure-and-properties of polymeric materials, their modeling and simulation, as well as some programming tools. These fields of research are intertwined in a way that the programming methods are used as ***tools*** for helping in the implementation of the simulation methods in ***understanding*** the ***performance*** of polymeric materials and their ***properties as connected to their structures***, which was applied in different application fields. The complete list of the author's contributions in these fields can be found in Appendix I at the end of this work.

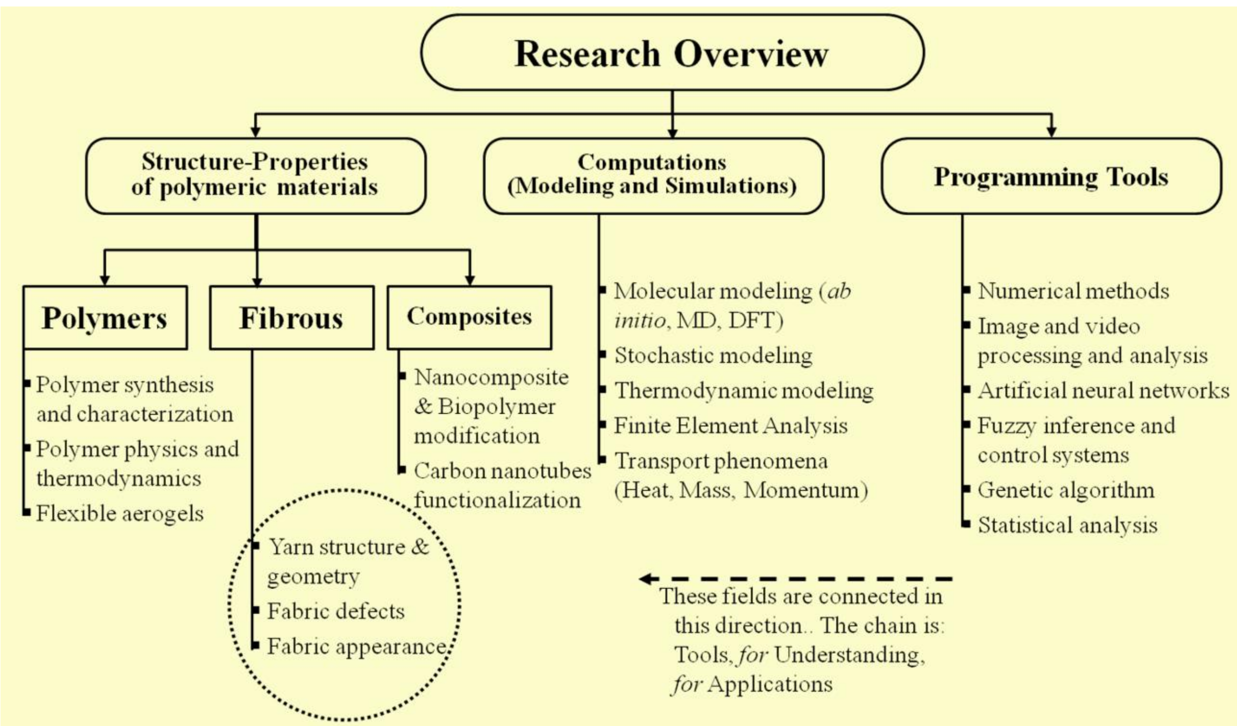

Figure 1. An overview of the author's main research interests and contributions (dotted circle highlights the topics that will be addressed in this work)

The latest research experiences of the author were developed at the Department of Textile Engineering, Mansoura University, Egypt and at the Department of Materials Engineering, Faculty of Textiles, Technical University of Liberec, Czech Republic. This research was more oriented towards the study of fibrous materials and their evaluation; where the author tried to contribute to the working environment by solving some of the problems emerged with the quality of fibrous structures, as presented below.

Fibrous structures and textile products have to conform to specific quality standards that determine their prices and the expected profit. Many tests on textile products are evaluated subjectively, where many criteria interact together to govern the final decision on the material's property. This subjective evaluation is usually carried out by human operators whose performance is susceptible to high degrees of uncertainty, because of the variability in experience among workers, work fatigue, change in mood…, etc. Most of these human-operated subjective evaluations are also dependent on the "observation" and the "visual alertness" of the worker. Therefore, methods were developed in this study to encounter these challenges that can be highlighted as follows:

1.2. The problem statement:

Many parameters that are considered in the evaluation of fibrous structures are performed ***manually*** through the ***observation*** of ***human operators*** who make their judgment based on ***subjective criteria***

1.3. The goal:

Replace the ***visual inspection*** and ***measurement*** processes during the evaluation of some fibrous structures with ***objective*** and ***smart systems*** that can work ***automatically***

1.4. The objectives:

To achieve the above goal, the presented work aims at:

- Developing objective evaluation criteria for the evaluation parameters
- Developing some algorithms that help to expedite the implementation of the selected criteria
- Developing computer vision techniques suitable for the final application
- Developing some "understanding" algorithms that imitate the human intelligence during the evaluation processes

1.5. Scope of the study:

1.5.1. Materials:

Although fibrous structures can extend to cover many materials, this study focuses the application on specific structures that are one-dimensional (yarns) and two dimensional (fabrics). The study covers the evaluation of fabric's faults during the production process and the fabric's pilling during the end-use application.

1.5.2. Technologies:

Yarns that were presented in this work were produced using ring-spinning, air-jet spinning, and some modifications on the ring-spinning frames to produce slub-yarns. This work also presented fabrics produced using the weaving as well as the knitting technologies.

1.5.3. Computation methods:

Image analysis, computer vision, and soft-computing are very wide fields that expand with the time due to the active research in these fields and results in new techniques from time to time. The scope of this study is the image analysis of binary and gray-scale images that were acquired through fixed frame images (still-images) or through the dynamic analysis of the image frames acquired with a video camera (high speed camera). The image segmentation was emphasized in this work as an essential prerequisite for image understanding. On the other hand, the artificial neural networks (ANN), and the adaptive neuro-fuzzy inference systems (ANFIS) were selected among the soft-computing techniques to be frequently implemented in this work.

1.6. Thesis format and organization:

This work is presented in ten chapters that are divided in three parts. Part I of this study presents the theory behind the work and consists of: this chapter on the work introduction and orientation, and two other chapters that cover the fundamentals of computer vision (chapter 2) and soft-computing (chapter 3). The aim of chapters 2 and 3 is not to discuss all the details behind the theory of compute vision (CV) and soft-computing (SC), but to touch very quickly on the basic knowledge that might be required for a reader without enough background in these fields. They also highlight some points that were not discussed in details in the published papers with special emphasis on the connection between these principles and their application in the textile field. Chapter 2 presents some image acquisition techniques relevant to the current work with more detailed description of the computed tomography (CT) as a promising technology that might solve some problems of the current imaging techniques. This chapter also discussed the digital representation of images which, once being digitized, allows the application of most traditional mathematical operations and algorithms for analyzing the images. The different stages required in image processing and computer vision for understanding the image content were presented, then the chapter concluded with listing the challenges facing the current state of computer vision and how these challenges directed the author through this work.

The difference between the soft-computing (SC) and the traditional hard-computing as well as the motivations behind the SC were presented in chapter 3 of this work. Only two SC algorithms were selected for presentation in this chapter; because they were used and implemented heavily in this study. The analogy of the artificial neural networks (ANN) to the biological nervous system was introduced in this chapter and the simplest neuron model was detailed. The ANN structures were presented and the feed-forward structure with back-propagation learning algorithm was emphasized, then the challenges and the critique of ANN were presented in the closing remarks of that section. Principles of the fuzzy logic and its controllers were introduced at the end of chapter 3 and the practical aspects were demonstrated with an example for replacing the subjective classing of cotton grades.

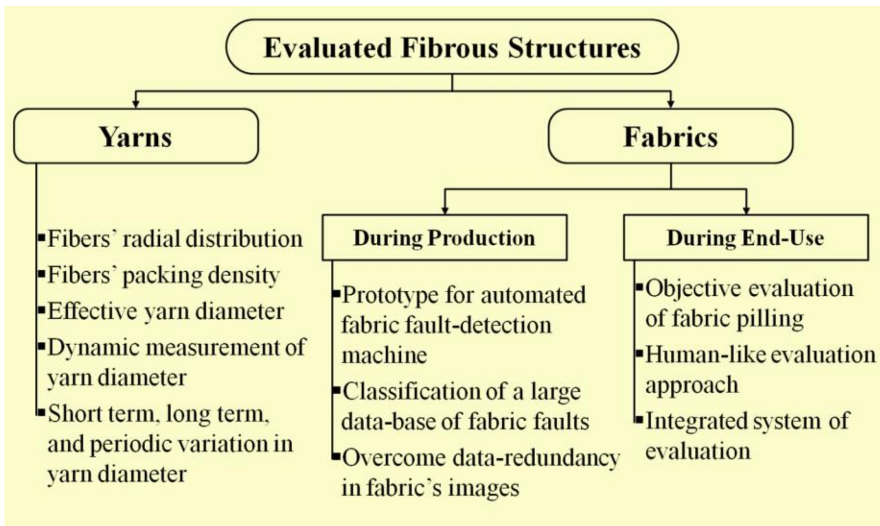

Figure 2. The application of computer vision and the computing & the soft computing algorithms in fibrous structures

An overview for Part II of this study is shown in Figure 2. This part presents a selected set of publications produced by the author with some applications of the image analysis (IA), computer vision (CV), and soft-computing (SC) in the evaluation of fibrous structures. To make it more readable and to have a unified style of this thesis, all papers were presented in the same format and font style regardless of the final formatting and type-setting of the journal. At the beginning of each chapter, a summary sheet of the paper was presented which briefly highlights: the paper's citation, the targeted problem, the objective(s), the scope, the computation algorithm, and the significance of the work. Finally, the summary sheet refers the reader to the demonstration of the software developed for the paper, if available. Also, at the end of each chapter (except chapter 4), minimized snapshots of the original paper as it appears in the final formatting of the journal were included.

The study of yarn geometry and its internal structure was presented in two chapters (chapter 4 and chapter 5) where chapter 4 presents the measurement of the packing density of fibers inside the yarn, the fibers radial distribution, the effective yarn diameter. This paper implements the Chan-Vese segmentation model for automatically allocating the contours of the yarn as well as the fibers inside. This segmentation algorithm allows the automation of the process which reduces the time required for the analysis and makes it independent from the subjective judgment of the human element. The method also avoids the approximations involved in the traditional methods by calculating the actual areas of the fibers and the yarn which makes it more accurate in determining the yarn packing density.

A dynamic and robust method for measuring the yarn diameter and its variation was introduced in chapter 5. The paper discussed in this chapter introduced a new effective image analysis method that reduces the time required for analyzing the yarn images; which becomes very essential when dealing with massive amount of yarn images captured by a high speed camera. The yarn diameter was measured at fixed intervals that assigned by the user which provides some degree of measuring flexibility that is missing with the commercial instruments for measuring the yarn diameter. The developed system was assigned the name DiaLib® with the advantage of being a "transparent system" for producing data that are usually obtained from expensive instruments with "black-box systems".

The evaluation of two-dimensional fibrous structures at the production stage was presented in chapter 6 and chapter 7. The algorithms for detecting and classifying the fabric faults during their production were presented in chapter 6. The work behind this chapter resulted in a machine prototype for automatic fabric fault detection and classification that was developed at Mansoura University, Egypt and a video demonstration for this prototype is included on the companion CD. During the fabric image analysis, a huge set of spatial as well as spectral features was extracted which requires a dimensionality reduction for this set of features by selecting the most representing ones. This was achieved by analyzing the features using the principle component analysis (PCA), as presented in chapter 7. PCA application on the combined (spatial and spectral) features set led to a 36% reduction of the original data size, while preserving 99% of the information in the original dataset. PCA application not only reduced the data size, but also enhanced the performance of the used soft-computing classifiers. Results of this work with high classification rate and short processing times are promising to apply these techniques for real time fabric inspection systems.

The last two chapters of Part II discuss the objective evaluation of fabric pilling, as an important appearance and aesthetic property. Chapter 8 presented a study on the pilling resistance evaluation of knitted fabrics while chapter 9 presented another study on woven fabrics. The algorithms developed in both chapters were also different where the image features used in each study as well as the implemented soft-computing classifiers were different. A simple set of the first-order statistical features was used in the study of the knitted fabrics and the classification was performed using an ANN system. The second-order textural features were used, for the first time, to analyze the pilling in woven fabrics, as presented in chapter 9. An algorithm for creating a features dataset required for the training and testing of the soft-computing classifier was described in this work; where a random noise was added to the limited number of fabric's standard images. The objective pilling classification of the woven fabric samples was performed using an adaptive neuro-fuzzy system (ANFIS) which showed a high performance in classifying the noised standard images as well as the actual fabric samples. Results of these studies showed high efficiency of the system that is independent of the fabric's structure or color. This suggests the system's validity in replacing the currently applied subjective pilling evaluation.

A final comment on the organization of this work is to inform the reader that this thesis is organized in a way that allows its handling from any point; because each chapter is written to be a stand-alone and does not have a direct dependency on other parts of the work. The theoretical part of this work (Part I) might be useful as a reference material that might be required for readers with limited background in the discussed fields, and can be skimmed (or skipped) by experienced readers. It is also important to point out that, there is a compact disc (CD) that was prepared as a companion material with this thesis. The CD allows an easy access in a digital form for the contents which includes:

- An electronic copy of this thesis; in a single file as well as in separate chapters for easier browsing
- A short video of the "fabric fault detection machine" prototype presented in this work
- The software programs developed during the work of each paper, if any, with some examples that allow the reader to test and use the programs
- Demonstrative videos for the developed software programs
- Other materials supporting the author's application for this habilitation work