1. PREFACE

This chapter contains an introduction to the presented work and an overview of the thesis.

1. 1 Introduction

Quality testing plays an important role in modern industry, producing a huge amount of elaborate technical products. Due to the increasing complexity of design and the high automation of technological processes it is becoming more crucial for industrial companies than it was in past decades. Constantly rising demands on product quality, cost pressure from customers, and the increased prices of raw materials are forcing manufacturers to explore novel ways of quality testing. The objective is to monitor in-process data as a means of indicating product quality and to react to unexpected technological disturbances as soon as possible. If a problem is not recognized quickly, many defective devices will be produced in the meantime. More and more complicated technology has resulted in more severe requirements for quality testing, even as it has caused an escalation of the information stream to be processed. Statistical methods used in the branch earlier [18, 54, 112] cannot provide adequate speed and quality of data analysis in response to a continuously strengthened load [135]. Another limitation of these tools is a lack of automation, adaptive behavior and flexibility, which has to be compensated by involving additional human resources. However, a hot trend in industry is the development of diagnostic systems with minimum functions for an operator. Therefore the need for automatic and intelligent methods of data analysis has arisen and seems likely to become ubiquitous in the near future.

To cope with this demand, Artificial Intelligence (AI) techniques, namely Artificial Neural Networks further referred to as NNs (in accordance with common practice the prefix «artificial» is omitted), have been recently applied to quality testing [2, 21, 41, 63, 89, 121, 137, 148, 178, 181, 183, 184]. NNs perform as trainable model-free estimators for high-dimensional nonlinear input-output mappings. In many practical applications, NNs turned out to be powerful tools for solving pattern recognition tasks. Automatic quality testing can also be considered as a pattern recognition task: different parameter measurements pertaining to end-production have to be analyzed in order to recognize deviations in technological modes causing fabrication of defects. The results of these measurements or tests then become inputs for a recognition system which can be implemented, for example, by means of an NN. In the general case, the aim of such a system is to interpret high-dimensional non-stationary data by generating appropriate input-output mapping. This task can be more precisely specified either as an approximation problem when an underlying continuous function f maps an input domain X to an output range Y, or as a classification problem that is the particular case of approximation when Y can take only discrete values i.e. the numbers of output classes. Both problems are typical of quality testing applications, but classification is predominant. For this reason, the scope of the present work will be confined to classification problems. The thesis is devoted to the development of an effective automatic neural classifier for industrial applications.

The ability of NNs to be adaptively trained in order to make decisions successfully even when the input data are noisy, incomplete, or inconsistent is their essential advantage, especially for industrial problems which are commonly characterized by very complex data sets. However, a disadvantage of NNs is their relatively low degree of automation. Although classification with NNs is widely used, not all neural algorithms possess the necessary properties to serve as automatic classifiers. Usually, most of them are applied rather in laboratories than in on-line processes directly. The main reason is that many popular NNs require for their application expert knowledge in the field or much experience. A great number of tuning parameters, as well as need for choosing an appropriate network topology, lead to lengthy experimental cycles performed to find the best NN configuration for a given classification task. This excludes the possibility of automation for such networks. Additionally, many NNs require retraining in respect to changing input data and therefore are unable to learn in non-stationary environments. Therefore the automation of NNs is one of the most important challenges in the design of modern intelligent systems. Interest in this area has been aroused recently [100, 135, 167]. In this context, the initial goal of the actual research was to develop a neural architecture that would be well-suited for automation and for use by non-experts. Extensive studies have shown that a large class of NNs, namely feedforward networks [188], cannot meet the requirements for an automatic classifier. The alternative is found to be Adaptive Resonance Theory (ART) networks, which possess several valuable properties in comparison with conventional feedforward networks: incrementally growing structure, stability of on-line learning, and extremely short training time.

Another disadvantage of NNs in respect to automatic classification in the quality testing field is their «black-box» nature. Generally, they are not suitable for initialization by expert knowledge and for verification or interpretation by humans, i.e. it is impossible to explain why certain inputs to an NN cause certain outputs. Though in solving quality testing problems, it is highly desirable to express the information learned by an NN as a set of linguistic rules in order to find unknown correlations between process parameters and product quality. Fuzzy Systems (FSs) which are based on the concept of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning can be used to improve the transparency of NNs in combined neuro-fuzzy models [38, 115, 151, 154, 155, 194]. Due to inheriting the merits of NNs: good learning and generalization abilities as well as parallel processing, and those of FSs: transparent behavior, ease of incorporating and extracting knowledge as well as performing simple computations, such models are very useful for automatic classification in industrial applications.

Consequently, a more specific class of the ART algorithms which combines ART principles and fuzzy logic is the one most appropriate for automatic realization. These networks named by the author ART Fuzzy networks (ARTFNs) are based on two major models: Fuzzy ARTMAP (FAM) [30] and Simpson's Fuzzy Min-Max Network (FMMN) [189, 190] they both will further be referred to as standard ARTFNs. Like the neuro-fuzzy models discussed above, ARTFNs join the properties of both neural and fuzzy approaches and therefore possess additional advantages such as interpretable information representation, unsophisticated implementation, few tuning parameters, and capability to produce fuzzy if-then rules as compared to ART in a broad sense. Although the standard ARTFNs may be seen as a proper basis for the development of an automatic classifier, some problems especially critical for automatic realization diminish their effectiveness. The most important of the limitations are the problem of manual parameter tuning and the category proliferation problem, i.e. fast structural growth of a network. The former problem is common for most classifiers no matter what type they are. It is also relevant for the standard ARTFNs although a small number of tuning parameters facilitates its solution. The latter problem leads to high memory demand for network storage, increases training and classification time and makes the knowledge extraction from a network impracticable due to a very large number of rules to be analyzed by humans. Naturally, even about thirty rules become already unreadable. Thus human interpretation of a fuzzy rule base implies extraction of as few rules as possible. The inadequately rapid growth of a network caused by category proliferation diminishes its on-line learning ability because resource requirements of the system may become unfeasible with the time. Obviously, these problems have to be solved prior to the use of ARTFNs as automatic classifiers.

In-depth literature analysis has shown that the category proliferation and parameter tuning problems of FAM and FMMN remain still unsolved in their later modifications. The objective of this thesis is to overcome the problems and to make ARTFNs suitable for automatic classification. It proposes a solution in the form of two algorithms: ART-based Fuzzy Classifier (AFC) and its automated extension AFCA. They improve classifying ARTFNs in several aspects: AFCs do not suffer from category proliferation, their information representation is compact, they are more robust to the parameter choice, more resistant to noise and more insensitive to the order of input presentation. Additionally, AFCs possess key features of FAM and FMMN including on-line learning and few tuning parameters as opposed to many other ARTFNs. AFCs have been verified by experimental results as being efficient in solving both benchmarks and industrial classification tasks.

1.2 Overview of the thesis

This thesis is divided into 7 chapters and is organized as follows. Chapter 1 states the objectives driving the actual research and includes an overview of the thesis. Chapter 2 contains an introduction to NNs from the perspective of automatic classification. It describes basic theoretical concepts, terminology, and different categorization schemes for NNs. Section 2.3 includes a brief overview of several basic neural architectures including ART. The next section undertakes a specification of desirable properties which should be inherent in the most effective NN for automatic classification. Then the presented neural architectures are compared on the basis of these requirements. Chapter 3 summarizes the theoretical background necessary to understand the main ARTFN properties and which is