A Study on the Application of Several Soft Computing Techniques to the Design of Fuzzy Diagnosis Systems for Rotating Machinery

Abstract

Nowadays, the implementation need of adequate maintenance programs in industrial machinery is amply justified by their related immediate economic benefits and improvement of safety standards. Consequently, Predictive Maintenance programs, which aim to detect and diagnose the most common machinery faults through the periodic or continuous measurement of some of its properties, have become a standard monitoring solution for machinery that may have a critical importance for production. Among the most widespread techniques used under this maintenance policy, the study of vibration or sound signals measured at specific points of the target machinery has proved to be one of the methods that can provide more significant diagnosis information. The interpretation of these vibration measurement for diagnosis purposes using several signal processing and feature extraction techniques, that is, Vibration Analysis, has gained in present times an extremely significant role for industrial maintenance. However, although an increasing number of faults can be accurately discriminated through new diagnosis techniques based on Vibration Analysis, the correct interpretation of these new methodologies also requires more expensive human training programs. Consequently, the automatization of this process through Artificial Intelligence and Pattern Recognition techniques is being the subject of an active research.

The research presented in this dissertation is a part of this trend, and aims to make a distinct contribution to the development of Knowledge-Based Systems for the automatic interpretation of machinery vibration data. In particular, we have focused our efforts in the automatic construction, from vibration data, of Fuzzy Pattern Matching (FPM)-based diagnosis systems, which have proved their special adequacy in those classification problems in which noise, uncertainty in the measurement process of the vibration data or subjectivity of the linguistic terms used in Knowledge Rules are important factors.

A systematic study of this problem has resulted in the identification of several research topics that must be handled with special concern. This dissertation is a compendium of theoretical studies and different implementation proposals to solve these issues. Our proposed solutions have adopted several techniques taken from the branch of Artificial Intelligence known as Soft Computing, which comprises the implementation of Intelligent Systems through Fuzzy Systems, Neural Networks and other computational techniques designed to deal with imprecision and partial truth.

This dissertation starts with some introductory chapters, that present a general overview of the field in which this research is included, and include a general appreciation of the contributions of previous research. Thus, in Chapter 2, a basic presentation of the most important topics in Vibration Analysis is offered. Following this, the vibration parameters that can be useful for diagnosis, which we call Vibration Symptoms, and which are extracted from the monitored machinery's vibration signals, are reviewed. A survey of the current research trends based on vibration and sound signals is offered, and the contribution made by this research is placed within this framework.
Another introductory chapter would be Chapter 3, in which the structure of the Fuzzy Diagnosis Rules to be constructed through an FPM methodology is explained. The matching process of the vibration symptoms extracted from the monitored machinery's mechanical signals with these diagnosis rules can also be found here. Using this technique, the three diagnosis steps of Fault Detection, Fault Isolation and Fault Identification can be processed.

The main novel contributions developed in this research are presented in Chapters 4 to 7. First, in Chapter 4, it is discussed how, as FPM is basically a criteria aggregation process, the adequate selection of the fuzzy connectives used herein can be of critical importance and needs careful consideration. A general overview of the existing fuzzy aggregation methods is presented and the special adequacy for diagnosis of compensated or mean operators is pointed out. In order to facilitate the selection process of the most adequate aggregation operator for a certain diagnosis task, a characterization method for these mean operators is proposed. Its use in determining the robustness or sensibility of a Fuzzy Diagnosis System is also proposed.

It is well known that Membership Function construction is an essential aspect in the design process of a Fuzzy Diagnosis System. In Chapter 5, this design task is approached through the evaluation of the probability density functions of the extracted vibration symptoms in their normal and fault state. In order to decide the most adequate parameters needed to define a Membership Function, a design method based on Dempster-Shafer Theory of Evidence has been developed.

Chapter 6 completes the previous two chapters by presenting two possible approaches to learn the general structure and importance weights of FPM rules. To face this problem, the practical implementation of two different learning paradigms are examined. On the one hand, a connectionist learning scheme, Knowledge-Based Networks, is considered. On the other, an approach based on evolutionary learning, Genetic Algorithms, is also studied. A comparative analysis is made on the advantages of applying both methods.

Although FPM diagnosis rules could already be extracted from vibration data using the methodology presented in chapters 4-6, its practical implementation would require in many cases a pre-selection of those Vibration Symptoms that have a greater significance for diagnosis. Chapter 7 introduces a symptom selection method based on Z. Pawlak's Rough Set concept. As Fuzzy Symptoms are being considered, the application of its extension to fuzzy values, what would be the Fuzzy Rough Sets theory, becomes a necessity. This chapter examines several Fuzzy Rough Sets proposals and evaluates their different characteristics. Several theoretical studies are performed, on which our objective of carrying out a Rough Sets analysis of Vibration Symptoms can be based. Among these studies, we examine the concept of Fuzzy Similarity Relation. As, for our purposes, this will be a concept of critical importance, the theoretical conditions in which these relations can be aggregated are thoroughly discussed. Another theoretical concept, $\beta$-Precision aggregation, is also developed for Rough Set Analysis of a large database of samples. Finally, the practical implementation of Fuzzy Rough Set theory for the selection of an optimal set of vibration symptoms and the preliminary construction of some diagnosis rules is also discussed.

This dissertation ends with the exposition of some practical results for these theoretical topics, which have been obtained on several vibration datasets. From these, some concluding remarks as to the validity of our proposals and their limitations have been elucidated.