Preface

A good maintenance strategy is essential to keep complex engineering systems safe. Historically, maintenance has evolved from post-failure repair to preventive maintenance to Condition-Based Maintenance (CBM). Preventive maintenance is an expensive and time-consuming process because it is carried out periodically regardless of the health state of systems. For modern complex systems with high reliability requirements, preventive maintenance has become a major expense of many industrial companies. CBM has recently received much attention as a cost-effective maintenance strategy, which is to perform maintenance only when needed. Prognostics and Health Management (PHM) is the key technology to accomplish CBM.

PHM is a new engineering approach that enables real-time health assessment of a system under its actual operating conditions, as well as the prediction of its future state based on up-to-date information, by incorporating various disciplines including sensing technologies, physics of failure, machine learning, modern statistics, and reliability engineering. It enables engineers to turn data and health states into information that will improve our knowledge on the system and provide a strategy to maintain the system in its originally intended function. While PHM has roots from the aerospace industry, it is now explored in many applications including manufacturing, automotive, railway, energy and heavy industry.

Since PHM is a relatively new research area, many researchers and students struggle to find a textbook that clearly explains basic algorithms and provides objective comparison between different algorithms. The objective of this book is to introduce the methods of predicting the future behavior of a system's health and the remaining useful life to determine an appropriate maintenance schedule. The uniqueness of this book lies not only in its introduction to various prognostics algorithms, but also in its explanations of their attributes and pros and cons in terms of model definition, model parameter estimation, and ability to handle noise and bias in data. Therefore, beginners in this field can select appropriate methods for their fields of application.

This book is suitable for graduate students in mechanical, civil, aerospace, electrical and industrial engineering, and engineering mechanics, as well as researchers and maintenance engineers in the above fields.

The textbook is organized into seven chapters. In Chap. 1, the basic ideas of PHM are introduced along with historical backgrounds, industrial applications, reviews of algorithms, and benefits and challenges of PHM. Before discussing individual prognostics algorithms in detail, Chap. 2 provides prognostics tutorials with a MATLAB code using simple examples. Even if simple polynomial models are used with the least-squares method, they contain most of important attributes of various prognostics algorithms. The tutorials include physics-based and data-driven prognostics algorithms to identify model parameters as well as to predict the remaining useful life. This chapter also introduces prognostics metrics to evaluate the performance of different algorithms as well as uncertainty due to noise in data.

A key step in prognostics is to convert the measured data from health monitoring systems into knowledge on damage degradation. Many prognostics algorithms utilize Bayes' theorem to update information on unknown model parameters using measured data. Chapter 3 introduces Bayesian inference with an explanation of uncertainty and conditional probability. For the purpose of prognostics, the chapter focuses on how to utilize prior information and likelihood functions from measured data in order to update the posterior probability density function (PDF) of model parameters. Depending on how information is updated, both recursive and total forms are discussed. The chapter ends with a method of generating samples from a posterior PDF.

When a physical model that describes the behavior of damage is available, it is always better to use it for prognostics. Chapter 4 presents physics-based prognostics algorithms, such as nonlinear least squares, Bayesian method, and particle filter. The major step in physics-based prognostics is to identify model parameters using measured data and to predict the remaining useful life using them. The chapter focuses on how to improve the accuracy of a degradation model and how to incorporate uncertainty in the future. The chapter ends by discussing issues in physics-based prognostics, which includes model adequacy, correlation between parameters, and quality of degradation data.

Even if physics-based approaches are powerful, many complex systems do not have a reliable physical model to describe the degradation of damage. Chapter 5 introduces data-driven approaches, which use information from observed data to identify the patterns of the degradation progress and predict the future state without using a physical model. As representative algorithms, the Gaussian process regression and neural network models are explained. Data-driven approaches share the same issues with physics-based approaches, such as model-form adequacy, estimation of optimal parameters, and quality of degradation data.

In Chap. 6, these prognostics algorithms are applied to fatigue crack growth problems to understand the attributes of different algorithms. In the case of physics-based approaches, correlation between model parameters, initial conditions, and loading conditions play an important role in the performance of algorithms. In the case of data-driven approaches, the availability of training data and the level of noise are important. Chapter 7 presents several applications of prognostics in practical engineering systems, including wear in a revolute joint, fatigue crack growth in a panel, prognostics using accelerated life test data, and fatigue damage in bearings.

MATLAB programs for different algorithms as well as measurement data used in the book are available on the companion website of the book http://www2.mae.ufl.edu/nkim/PHM/. Each chapter contains a comprehensive set of exercise problems, some of which require MATLAB programs.

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