Preface

Operational modal analysis (OMA) aims at identifying the modal properties (natural frequencies, damping ratios, mode shapes, etc.) of a structure using vibration response measurements only. The possibility of doing so without knowing the input forces is exciting from both a theoretical and practical point of view. It significantly enhances the feasibility and reduces the cost of obtaining in-situ information about structures. Together with the advent of sensing, data acquisition and computer technology, the bar to enter the community of vibration testing or related research is disappearing. Activities are booming in all directions, e.g., theory development, experimentation and applications; and spanning across civil, mechanical, aerospace and electrical power engineering.

I started exploring OMA in an industrial project in 2008 when I was looking for a conventional method to identify the modal properties of several tall buildings from acceleration time histories during typhoons. At that time the literature was already quite mature, with many smart ideas of coming up with an estimate for modal properties from apparently random vibration time histories that one can hardly make any sense of. After experimenting with different methods and data under various situations (some similar and some different) I soon realized that there was a significant scatter in the estimates, despite the fact that the fit between the theoretical and empirical statistics (from which the estimates were obtained) appeared quite reasonable in each case. Damping ratio was the quantity of most interest in the project, but its scatter was quite large, which inevitably undermined the value of the work.

The main issue with the scatter was perhaps not so much with its existence but rather with the lack of understanding, which motivated subsequent research in OMA. The objective is not so much to come up with another estimate for the modal properties (there are already many methods) but rather to have a scientifically sound method that tells how large their 'uncertainty' is; and, if possible, how it depends on the factors that can be quantified.

Uncertainty is as a lack of information. Using probability for quantification, Bayes' theorem provides the fundamental principle for processing information and hence uncertainty. It yields the probability distribution of modal properties conditional on available data and modeling assumptions, naturally addressing both estimation and uncertainty quantification in OMA. The concept is metaphysical but very useful for decision making. The mathematics is not trivial, but it can be worked out and made efficient in the form of computer algorithms. After some years of development, I believe the algorithms for Bayesian OMA are now ready for industrial applications and the theory allows us to understand how identification uncertainty depends on test configuration. Of course, there are still many uncertainty-related problems in OMA and applications that have yet to be addressed. It will require concerted efforts in the future.

Adopting a Bayesian perspective means that we need to be clear about what assumptions we make on OMA data, because our conclusions are all conditional on them. Results are as good as assumptions. This is generally true but is particularly important to bear in mind when making Bayesian inference. It is tempting to believe that the calculated uncertainties are universal numbers; they are not. Throughout this book, the assumptions on OMA data are invariably the same. They are the conventional ones used in structural dynamic analysis and design, e.g., linear classically damped dynamics and stochastic stationary response.

This is intended to be a book for learning the basic assumptions and probabilistic modeling of ambient vibration data, how to make Bayesian inference effectively, and identification uncertainty in OMA. The primary audience are graduate students and researchers, although practitioners should also find the application part of the book a useful reference. Even if Bayesian OMA algorithms may not be adopted, I hope the book can still arouse interests in field testing and provide materials for understanding ambient vibration data and uncertainties in OMA.

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