Mechanical Systems and Signal Processing 117 (2019) 453–482

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Review

# Transmissibility-based system identification for structural health Monitoring: Fundamentals, approaches, and applications

Wang-Ji Yan *, Meng-Yun Zhao, Qian Sun, Wei-Xin Ren *

*Department of Civil Engineering, Hefei University of Technology, Hefei, Anhui 23009, People's Republic of China*

ARTICLE INFO

*Article history:*
Received 25 November 2017
Received in revised form 13 June 2018
Accepted 27 June 2018

*Keywords:*
Transmissibility function
Structural health monitoring
Modal analysis
Damage detection
Model updating

ABSTRACT

The difficulty of achieving controlled input has led to the development of new output-only structural health monitoring (SHM) approaches. Without measuring the input or assuming a specific input model, a transmissibility function (TF) as a mathematical representation of the output-to-output relationship has proven to be an attractive tool in SHM. The state of the art and challenges to TF analysis that cast SHM in the context of a system identification (SI) paradigm are reviewed and discussed in this study. This review starts with an overview of the fundamentals of TFs by illustrating its categories, connections with frequency response functions (FRFs), and basic properties. By categorizing TFs as local and global, this literature review limits the practice of various methodologies to the following key aspects: modal analysis, damage detection, and model updating. A brief treatment of the basic ideas is presented while a comprehensive and critical explanation of their contents is not attempted. Based on the review, existing studies are discussed, highlighting gaps requiring additional work and possible future trends for TF-based system identification.



**Contents**

1. Introduction . . . 454
2. Fundamentals of TFs . . . 455
   2.1. Categories of TFs . . . 455
   2.2. Connecting TFs with FRFs . . . 455
   2.3. Basic properties of TFs . . . 456
3. Review of TF-based OMA . . . 456
   3.1. Introduction to modal analysis . . . 456
      3.1.1. Experimental modal analysis (EMA) . . . 456
      3.1.2. OMA . . . 456
      3.1.3. Open issues on OMA . . . 457
   3.2. Review of TF-based OMA . . . 457
      3.2.1. Local TF-based OMA . . . 457
      3.2.2. Global TF-based OMA . . . 461
   3.3. Case study and discussions . . . 462
      3.3.1. White-noise excitation . . . 463
      3.3.2. Harmonic excitation . . . 464

* Corresponding authors.
*E-mail addresses:* civilyanwj@gmail.com (W.-J. Yan), renwx@hfut.edu.cn (W.-X. Ren).

https://doi.org/10.1016/j.ymssp.2018.06.053
0888-3270/

4. Review of TF-based structural damage detection . . . . . 466
4.1. Damage detection based on local TF . . . . . 466
4.1.1. Damage detection based on damage indicators (DIs) . . . . . 466
4.1.2. Damage detection incorporating novelty detection schemes . . . . . 469
4.2. Damage detection driven by global TF . . . . . 469
4.2.1. Damage detection with damage indicators . . . . . 469
4.2.2. Response reconstruction-based damage detection approaches . . . . . 470
4.2.3. Damage detection using global TF in wavelet and state-space domain . . . . . 470
4.3. Case study and discussions . . . . . 470
5. Review of TF-based structural model updating . . . . . 473
6. Future outlook . . . . . 473
6.1. Consideration of the effect of uncertainty . . . . . 473
6.1.1. Local TFs . . . . . 473
6.1.2. Global TFs . . . . . 475
6.2. Consideration of the effect of nonlinear behavior . . . . . 475
6.2.1. Frequency domain ARX approach . . . . . 476
6.2.2. NOFRF approach . . . . . 476
7. Other applications . . . . . 477
8. Conclusions . . . . . 477
Acknowledgements . . . . . 478
References . . . . . 478

## 1. Introduction

Structural health monitoring (SHM) has attracted increasing attention in recent decades [1–7]. The process of SHM usually involves data acquisition, damage-sensitive feature extraction, and condition assessment. The progress in hardware development has enabled the deployment of dense sensor arrays at a relatively low cost, thereby generating a large bulk of data [8]. Therefore, advanced computational methods are of practical importance to handle the wealth of information by translating it into an effective system representation. The task of transferring raw data into salient features indicative of current and future performance usually necessitates adoption of appropriate system identification (SI) approaches [9].

In a broader context, in the technical literature, SI is a general term that refers to the extraction of information about structural behavior directly from experimental data [9]. It can be implemented either by building dynamic models from measured data or without the use of a model. In the context of SHM, SI mainly includes two branches: modal-parameter identification and physical-parameter identification. Modal-parameter identification aims to identify a structural system's modal parameters, such as natural frequencies, damping ratios, and mode shapes, while physical-parameter identification involves the extraction of useful information related to stiffness, mass, and damping. The results produced by SI are expected to be further utilized to assess infrastructural health status and damage information, which allows engineers and asset owners to improve the safety and serviceability of critical structures [10–15].

The rationale behind SI is making inference about the parameters of a mathematical model based on the observed measurements and the input of a system. One common task is to fit a theoretical model to an experimental model estimated from applied excitations and response measurements, as visualized in Fig. 1. Different mathematical models in the time, frequency, and time–frequency domains have been introduced to the SI field in recent years. Frequency response functions (FRFs) are commonly used to characterize the most fundamental frequency-dependent input–output relationships of a dynamic system [16–20]. An input–output technique would typically be more accurate, but the input data are not always available. The difficulty of achieving controlled input has led to the development of new output-only SHM approaches. Therefore, the problem of SI using output-only data usually arises, spurring the adoption of new techniques. Transmissibility functions (TFs), which can avoid measuring the input and assuming specific models for the input, has proven to be an attractive tool.

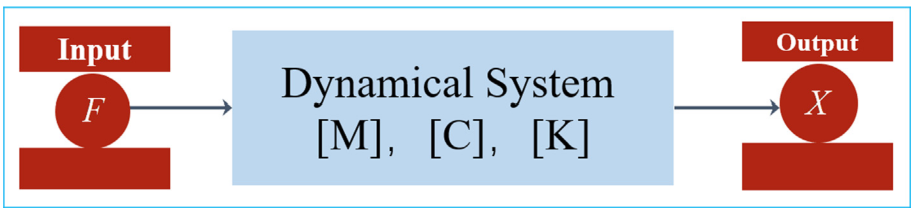


**Fig. 1.** Vibration-based system illustration.