TRANSACTIONS OF THE ASME

JOURNAL OF VIBRATION AND ACOUSTICS

PUBLISHED QUARTERLY BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS • JANUARY 1997

Integrated Estimation/Identification Using Second-Order Dynamic Models

J. L. Crassidis
National Research Council
Postdoctoral Fellow.
NASA-Goddard Space Flight Center,
Greenbelt, MD 20771

D. J. Mook
Associate Professor.
Dept. of Mech. and Aero. Engr.,
State University of New York at Buffalo,
Buffalo, NY 14260
Mem. ASME

An algorithm is presented which accurately identifies multi-input-multi-output systems characterized by vibrating structures. More specifically, an identification technique is integrated with an optimal estimator in order to develop an algorithm which is robust with respect to measurement and process noise. The unique functional form of the integrated approach utilizes systems described by second-order models. Therefore, theoretical mass, damping, and stiffness matrices, associated with lumped parameter models, are tailored with experimental time-domain data for system estimation and identification. This leads to an algorithm that is computationally efficient, producing realizations of complex multiple degree-of-freedom systems. The combined estimation/identification algorithm is used to identify the properties of an actual flexible truss from experimental data. Comparison of experimental frequency-domain data to the predicted model characteristics indicates that the integrated algorithm produces near-minimal realizations coupled with accurate modal properties.

Introduction

Combining theoretical models with experimental data is an important aspect for both system identification and estimation. More specifically, estimation techniques utilize past observations to estimate response characteristics which generally minimize the expectation of the square of the error between the actual measurements and the estimated signal. Common linear estimation algorithms include, the Weiner filter (Weiner, 1949), maximum likelihood techniques (Iliff et al., 1984), and least square techniques (Bode and Shannon, 1950). The Kalman filter (Kalman, 1960) expands the Weiner problem by incorporating state-space formulations in the filter design. This algorithm, along with its derivatives, not only filters noisy measurements, but provides state estimates of the physical system. Also, the Kalman filter algorithm can be expanded for systems described by linear second-order matrix equations (Hashemipour and Laub, 1988). This is extremely useful in the study of vibrational problems such as large space structures.

Time domain techniques are useful in identifying the modal properties of a flexible structure. Realized state-space models can be used for various control designs such as, LQR, LQG, and/or H_∞ algorithms. A few identification algorithms of particular interest include, AutoRegressive Moving Average (ARMA) models (Astrom and Eykhoff, 1971), Least Square algorithms (Smith, 1981), the Impulse Response technique (Yeh and Yang, 1987), the Polyreference method (Leuridan and Vold, 1983), and Ibrahim's Time Domain (Ibrahim and Mikulcik, 1977) technique. The Eigensystem Realization Algorithm (Juang and Pappa, 1985) expands upon these algorithms by utilizing singular value decompositions in order to better identify physical modes from time domain measurements. In most circumstances, the identification of SISO models from experimental data can easily be obtained. However, since transmission zeros impose strict mathematical constraints on system matrices, *minimal* realizations of MIMO systems are usually difficult to obtain experimentally. Possible sources of error include: sensor and instrumentation noise, slight nonlinearities inherent in the structure, and/or background vibration. Therefore, for system identification of flexible structures, multiple experiments are usually performed in order to improve mathematical models. However, this requires extensive computational time and effort.

In recent years, several techniques have been developed which expand upon analytical models to conform with experimental data. In particular, finite-element models of a given structure are compared with experimentally measured data in order to update second-order models (see, e.g., Heylen, 1990, and Minas and Inman, 1990). The experimental data is usually in the form of modal data, such as natural frequencies, damping ratios, and mode shapes. In almost all circumstances the modal data is incomplete since measurements are usually taken along a limited number of selected locations. This increases the complexity of updating analytical models, since finite-element models are generally of larger order than the experimentally measured modes (Heylen, 1990). In the case of MIMO models, the complexity of finite-element updating increases since accurate (symmetric) positive definite stiffness and positive semi-definite damping matrices are usually not guaranteed to have the same physical significance as the original modeling (Minas and Inman, 1990). Also, several iterations of the modified system matrices are usually required in order to achieve satisfactory results.

The identification algorithm developed in this paper identifies accurate (near minimal) state-space realizations of a structure from only one set of experimental data. This algorithm combines an optimal state estimation routine, known as the Minimum Model Error (MME) estimator (Mook and Junkins, 1988), with the Eigensystem Realization Algorithm (ERA) in order to provide robust features for MIMO identification. The advantages of the MME estimator are: (i) the model error is assumed unknown and is estimated as part of the solution; (ii) the model error may take any form including nonlinear; and (iii) the algorithm is robust in the presence of high measurement noise. Therefore, accurate state estimates can be obtained and used during the identification process.

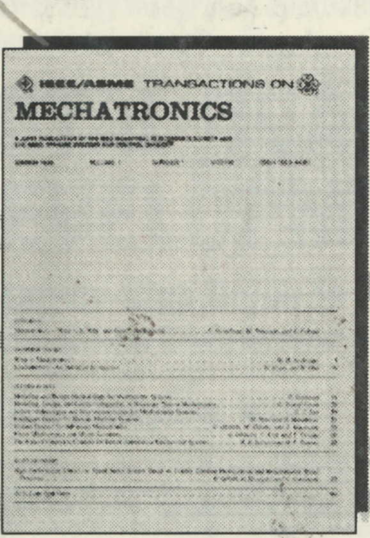
The combined MME/ERA identification algorithm has been successfully applied to numerous applications (see, e.g., Roemer and Mook, 1990, and Mook and Lew, 1988). Recent work by Roemer and Mook (1992) utilized this algorithm to identify the modal properties of damped structures using measurements with a high noise content. However, only modal properties (natural frequencies and damping ratios) of SISO systems were

---

Contributed by the Technical Committee on Vibration and Sound for publication in the JOURNAL OF VIBRATION AND ACOUSTICS. Manuscript received Feb. 1993. Associate Technical Editor: M. Ahmadian.

ASME International

TRANSACTIONS ON MECHATRONICS



MO GN SYSTEM INTEGRATION ROBOTICS
SENSORS INTELLIGENT CONTROL
MA VIBRATION AND NOISE CONTROL MICRO
DEV NTROL OPTO-ELECTRONIC SYSTEMS
AUT S OTHER APPLICATIONS MODELING
AND I INTEGRATION ROBOTICS
ACTUATORS AND SENSORS INTELLIGENT CONTROL

Published as a cooperative effort between IEEE and ASME, this groundbreaking publication focuses on the integration of technical engineering with electronic and intelligent computer control in the design and manufacture of industrial products and processes. A practical publication with an applications orientation, Mechatronics presents both state-of-the-art research and recent technical advances from internationally recognized experts.

AREAS COVERED INCLUDE:
flexible automation, applications of neural networks and fuzzy systems, concurrent engineering, artificial intelligence, expert systems, factory communications, manufacturing system architecture, and industrial and process automation

A SAMPLING OF RECENT ARTICLES:

- Modeling and Design Methodology for Mechatronic Systems
- Modeling, Design, and Control Integration: A Necessary Step in Mechatronics
- Sensor Technologies and Microsensor Issues for Mechatronics Systems
- Intelligent Control for Human-Machine Systems
- Motion Control for Advanced Mechatronics
- Micro Mechatronics and Micro Actuators
- The Role of Electronic Controls for Future Automotive Mechatronic Systems

SUBSCRIBE NOW!
ISSN: 1083-4485
$275
Published: March, June, September, December

MAIL
ASME / 22 Law Drive
P.O. Box 2900
Fairfield, NJ 07007-2900

TELEPHONE
US & Canada 800-843-2763
Mexico +95-800-843-2763
Outside No. America +1-201-882-1167

FAX
+1-201-882-1717 or
+1-201-882-5155

E-MAIL: infocentral@asme.org

ISSN 1048-9002
JOURNAL CODE JL
ISSUE CODE 9701