Book Reviews

Advances in Smart Technologies in Structural Engineering J. Holnicki-Szulc, C. A. Mota Soares (New York: Springer-Verlag, 2004). *Reviewed by Tracy Kijewski-Correa*

I. Background and Future of "Smart Structures"

Within the last few decades there has been a growing fusion of the disciplines of electrical, civil, and aerospace/mechanical engineering to develop a new generation of "smart structures." Generally speaking, such "smart structures" have the ability to adapt their structural characteristics to mitigate excessive response, monitor their own condition, perform self-diagnosis and even self-repair. Though these topics are of interest to a number of professional organizations (IEEE, ASME, ASCE, etc.), readers may particularly find the proceedings of the International Society for Optical Engineering's (SPIE) Annual International Symposium on Smart Structures and Materials to be a valuable resource that chronicles the lineage of the "smart structural" movement over the last decade.

An extensive literature review in [2] highlights some of the developments in the aerospace/mechanical and civil engineering communities, focusing specifically on structural control, where considerable advancements have been made in active, semi-active and hybrid methodologies to minimize vibrations for improved tracking (aerospace) or to reduce response of buildings or bridges for life safety (civil). Despite the successes of applied structural control in Japan [3], U.S. civil applications have remained largely passive, though with continued interest in semi-active schemes, smart materials and adaptive/intelligent control. Consistent with the goal of providing safe public infrastructure, a growing number of researchers have now directed their efforts toward extending the condition assessment and diagnostics branches of "smart structures," i.e., structural health monitoring (SHM), to large civil systems.

While the use of embedded sensing to provide feedback on the condition or status of mechanical systems, e.g., automobiles, industrial machinery, and aerospace systems, has long been commonplace for diagnostics and maintenance, the notion of continuous SHM has yet to be realistically extended to one of the major societal investments: civil infrastructure, i.e., roadways, buildings and bridges, which have manifested an alarming rate of premature decay and threats in extreme events. As a result, within the last decade, researchers have proposed SHM strategies to replace manual inspection processes with embedded sensors and automated assessment frameworks. Despite many of the existing developments in the aerospace/mechanical fields, the unique needs and constraints of civil infrastructure necessitate hardware advancements in high-quality, low-cost sensors and low-power wireless sensor networks in parallel with the development of more accurate system identification/damage detection techniques based on global response data [1] or localized detection techniques embeddable on a wireless sensor's on-board processor. In particular, these system identification approaches must effectively diagnose the presence of damage, its location, severity and remaining service life on complex structures based on limited sensor data collected in relatively harsh environments. In contrast to this form of global, unattended damage assessment, more localized and attended nondestructive evaluation (NDE) techniques using acoustic and ultrasonic methods to identify material imperfections are an equally vital area of research in the SHM field. As this brief introduction indicates, a broad spectrum of research needs are encompassed in the "smart structural" movement, which promises to revolutionize the interface between innovative sensing technologies, control and built machinery/civil infrastructure.

The reviewer is with the Structural DYNAmics and MOnitoring (DYNAMO) Laboratory, the University of Notre Dame, Notre Dame, IN 46556 USA (e-mail: tkijewsk@nd.edu).

Digital Object Identifier 10.1109/TAC.2005.858631

II. The Book

Given the expanse of research related to the field of "smart structures," no single text can fully address the research state-of-the-art for all the disciplines involved. Thus, this book focuses on the eight invited lectures at AMAS and ECCOMAS Workshop/Thematic Conference SMART'03 on Smart Materials and Structures in Jadwisin, Poland, September 2–5, 2003. As these invited lectures broadly covered the fields of structural control, vibration control and dynamics, damage identification and smart materials, they are representative of a number of the fundamental problems being pursued by the "smart structures" community. The specific content of each paper is next summarized, grouping them into the general subject areas of: a) structural control and b) structural health monitoring and damage detection.

A. Structural Control

"Fuzzy Chip Controllers and Wireless Links in Smart Structures" by Casciati and Rossi respectively touches on two topics of particular interest in the structural control and SHM communities. In particular, fuzzy control is important given the uncertain and incomplete information often available in practical applications, particularly when attractive wireless communications are used (known to suffer from packet loss). Thus, the authors present a very natural marriage of technologies for "smart structures." Unfortunately, this paper reads much like a user manual for the fuzzy chip controllers developed by the authors, with a heavy focus on hardware details and functional capabilities that may be wasted on many readers.

Gaul *et al.* next present "Semi-Active Friction Damping of Flexible Lightweight Structures," which addresses the long-standing problem of supplementary energy dissipation in lightly-damped structures. The authors present a well laid-out, logical methodology that highlights the distinction between active and semiactive approaches for effective control of friction joints in large space structures (trusses). Examples demonstrate the effectiveness of the proposed semiactive strategy in comparison to active control, though it is also interesting to note that for the large amplitude portion of the impulse response, the energy dissipated by the passive friction joints is equivalent to the semi-active joints. As in the case of many lightly damped structures, the addition of some damping, even at suboptimal levels, may be sufficient to mitigate large-amplitude response.

Holnicki-Szulc *et al.*, in "Design of Adaptive Structures under Random Impact Conditions," then address the intriguing area of adaptive structures for the development of highly efficient designs robust enough to safely handle large impacts from a variety of sources. The approach utilizes the semiactive detachment or deformation of structural elements to achieve elastoplastic behaviors that efficiently dissipate energy to minimize acceleration levels. While the authors demonstrate the potentials of the work on simplified structural elements, the challenge here lies in practical implementation, given the complexity of actual structures and the need to determine a priori the appropriate adaptation and redistribution schemes for all possible extreme loadings. Further, the need to respond in real-time in an anticipatory fashion to mobilize the adaptation of active elements is particularly challenging given the short duration of the impulsive-type loading under consideration.

"Controllability and Asymptotic Problems in Distributed Systems" by Telega returns to fundamental issues of structural control in relation to perturbation problems, i.e., asymptotic problems involving small parameters ϵ tending to zero. The author begins the discussion with some preliminaries of the Hilbert Uniqueness Theorem (HUM) followed by an account of the controllability problems associated with equations having singular perturbations. A major section of the paper then focuses on control of wave and linear elastic equations in thin domains followed by a review of the work in the area of homogenization and controllability. Here, it was demonstrated that although the combination of homogenization and HUM promised a solution to the problem of exact controllability in limit problems ($\epsilon \rightarrow 0$), issues still remain in boundary controllability. In total, the author does great justice to the issue of controllability in such asymptotic systems with detailed theoretical developments and a hearty literature review that reinforces not only the work that has been done in the area, but also that which remains.

B. *Structural Health Monitoring and Damage Detection*

Ostachowicz and Krawczuk provide a more traditional finite-element based approach to the dynamics of compromised structural elements such as rods, beams and plates. The focus of "Damage Detection of Structures Using Spectral Element Method" is on damage and delamination in simplified systems using a spectral element approach that is inherently better suited to representing wave propagation dynamics. The authors develop idealized damage models for varying structural elements and, through a series of numerical simulations, demonstrate the variability in time series response induced by small levels of damage, e.g., cracks 5% deep. Though clearly demonstrating that differences in damaged and undamaged specimens can be detected using the spectral element approach, these have only been validated numerically. Further, while changes between damaged and undamaged states were noted, it was only speculated how these changes could be used to quantify the location and extent of damage. As such, what is presented in this chapter shows some promise but clearly the need for further investigation.

Preumont *et al.* next present "Spatial Filtering with Discrete Array Sensors and Distributed PVDF Films," which demonstrates the issues of spatial aliasing when discrete sensor arrays are utilized as modal filters. Due to the shortcomings of discrete sensor arrays in the high frequency range, the use of a distributed sensor is proposed. To overcome practical limitations of tailoring the piezoelectric properties of this 2-D distributed sensor, the authors introduce a porous electrode concept, based on the assumption that the distributed sensor may be visualized as an infinite number of discrete sensors and validate this scheme experimentally. Thus, the paper represents an alternative approach to modal filtering with distributed sensors that proves to be far more intuitive and in some respects practical for implementation.

Staszewski's "Structural Health Monitoring Using Guided Ultrasonic Waves" provides quite an exhaustive review of the theory and application of guided ultrasonic waves for SHM, examining both contact and noncontact sensing approaches. The extensive references provide the reader with a healthy resource for more detailed information and applications of the technology. The paper is particularly helpful in its evaluation of strengths and weaknesses of various transducer technologies and practical concerns in their applications, such as physical attachment, optimal placement and appropriate excitation type. The paper then moves toward issues of modeling and signal processing tools for damage detection. Though the paper is heavily focused on the transducer aspects, while lacking significant demonstration of actual damage detection, the references and range of materials presented encompass a spectrum of applications from aerospace/mechanical to civil engineering that should be of great use to any seeking a state-of-the-art review.

Uhl's "Mechatronics in Vibration Monitoring and Control" first presents the interdisciplinary concept of mechatronic design. The author then selects two "smart structural" applications to demonstrate this design principle. The first is a "smart sensor" with on-board processing capability for determining operational loads from response measurements. The author gives detailed discussion of software available for simulation and design of "smart sensors," as well as an overview of requisite hardware; however, the inverse problem of load estimation from response is not trivial and is given limited treatment by the author. The second application focuses on a mechatronic device for automatic shaft balancing by integrating a controller into the hardware and software design to produce a "smart sensor" that can not only detect damage but also correct for it in mechanical systems. Perhaps the most important theme of the paper relates to the mechatronic design philosophy itself and the need to better integrate the SHM system with the structure being monitored early in the design process.

III. Concluding Evaluation

The basic principle of embedded sensing providing some level of feedback for decision making in control or diagnostics is a unifying theme in this collection of papers. Fittingly, given the diversity of "smart structures" research, it is expected that the topics and applications presented in this book can be by no means exhaustive. Instead, the book attempts to demonstrate this very diversity by chronicling developments from more traditional control theories and their applications to NDE and SHM to sensor development. Understandably, given the audience for the conference, the damage detection and monitoring applications presented are restrained to mechanical systems and simplified structures, e.g., beam and truss elements. Thus, it can be inferred that one area lacking in this compendium is any discussion of system identification/damage detection approaches for unattended, continuous monitoring of complex systems often requiring "blind" system identification based on limited global outputs without any knowledge of the input excitation.

Being a collection of papers on diverse topics, one should not expect continuity in content or style. As such, the contributions of the various papers have utility for the general readership in varying degrees, e.g., Staszewski and Telega utilized their lectures as an extensive review of current efforts in the community to serve as a resource document, whereas other others used this opportunity to showcase developments within their research groups in either a highly practical or theoretical fashion. Thus, in order to serve as an educational/state-of-the-art resource, this text should include more presentations of the former type. At present, the text falls somewhere between this format and an archival journal, where a researcher may be drawn to one but likely not all of the collected papers. Still, this book emphasizes the unique and promising solutions to societal problems that can surface when diverse disciplines of civil, aerospace/mechanical, and electrical engineering come together.

References

[1] S. W. Doebling, C. R. Farrar, M. B. Prime, and D. W. Shevitz, "Damage identification and health monitoring of structural and mechanical systems from changes in their vibration characteristics: A literature review," Los Alamos National Laboratory, Los Alamos, , LA-13 070-MS, 1996.

[2] G. W. Housner, L. A. Bergman, T. K. Caughey, A. G. Chassiakos, R. O. Claus, S. F. Masri, R. E. Skelton, T. T. Soong, B. F. Spencer, and J. T. P. Yao, "Structural control: Past, present, and future," *ASCE J. Eng. Mech.*, vol. 123, no. 9, pp. 897–971, 1997.

[3] A. Kareem, T. Kijewski, and Y. Tamura, "Mitigation of motion of tall buildings with recent applications," *Wind Struct.*, vol. 2, no. 3, pp. 201–251, 1999.

What must a book review contain? Like all works of art, no two book reviews will be identical. But fear not: there are a few guidelines for any aspiring book reviewer to follow. Most book reviews, for instance, are less than 1,500 words long, with the sweet spot hitting somewhere around the 1,000-word mark. (However, this may vary depending on the platform on which youâ€™re writing, as weâ€™ll see later.) In addition, all book reviews share some universal elements. These include: A concise plot summary of the book. A book review is a form of literary criticism in which a book is merely described (summary review) or analyzed based on content, style, and merit. A book review may be a primary source, opinion piece, summary review or scholarly review. Books can be reviewed for printed periodicals, magazines and newspapers, as school work, or for book web sites on the Internet. A book review's length may vary from a single paragraph to a substantial essay. Such a review may evaluate the book on the basis of personal