SYSTEMS IDENTIFICATION TECHNOLOGY DEVELOPMENT FOR LARGE SPACE SYSTEMS

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SYSTEMS IDENTIFICATION DEVELOPMENT

The need for systems identification in large aerospace structures arises because of ignorance of the structural parameters and changing control regimes. In particular, the dynamic characteristics of large, flexible spacecraft cannot be determined through ground tests and there is a basic need for a control system which can start with the best available system parameters and self-tune to a set which gives stable system response.

The objective of the research program established under RTOP 506-62-43 is to develop a methodology for synthesizing systems identification, both parameter and state, estimation and related control schemes for flexible aerospace structures with initial emphasis on the Maypole hoop-column antenna as a real world application. This important area of systems technology is an unsolved problem for large, flexible space structures with changes in configuration. The area intersects the disciplines of the mathematical theory of partial differential equations, lumped and distributed systems theory, adaptive control the high order systems, and structural dynamics mathematical modeling, to name a few, and requires a multidisciplinary team of researchers to impact the foregoing objective.

The basic structure for such a team has been established through a university research grant (NAG-1-171) awarded April 1, 1981, to the Rensselaer Polytechnic Institute, Troy, NY, with Professor Mark Balas of the Computer and Systems Engineering Department as Principal Investigator. The personnel and expertise of the researchers supported under the grant are:

• Dr. Mark Balas, RPI	Nonadaptive control of large scale or distributed systems with mechanically flexible structures (ref. 1)
• Dr. Howard Kaufman, RPI	Adaptive control of multivariable systems (ref. 2)
• Dr. Alan Dearochers, RPI	Model order reduction techniques (ref. 3)
• Dr. Robert Loewy, RPI (added September 1, 1981)	Structural dynamics and modeling
• Dr. Thomas Banks, Brown University, Providence, Rhode Island	Consultant in mathematics and numerical methods

Since the grant effort began only recently, results to date are largely conceptual. Parameter estimation schemes for lumped multi-input multi-output systems will be extended to high order or distributed systems where possible and examined for sensitivity to spillover effects. The area of adaptive control is being surveyed for strengths and weaknesses in regard to Large Space Systems. At this writing the Luders-Narendra adaptive observer (ref. 4) and a modified autoregressive moving average (ref. 5) method appear promising. Additionally, Dr. Loewy is developing a lumped parameter model of the hoop-column antenna which in complexity will lie somewhere between the finite-element and partial differential equation representations. The modeling approach proposed by Dr. Loewy is discussed in the next section. It is felt that such a model will be more amenable to modern systems theory identification techniques than a finite-element model. Until this model is completed, techniques are being analyzed on a stretched membrane example which is felt to be generic to the hoop-column structure. Dr. Banks has developed a numerical approach (refs. 6 and 7) to system identification and control of distributed systems which appears promising for large space systems. It is intended that he apply his approach to a partial differential equation model of the hoop-column antenna.

In the future, the most promising control and identification techniques pinpointed in the first year of the grant will be applied to the lumped model developed by Dr. Loewy. It is expected that a separate grant will be awarded for the application of Dr. Bank's methodology.

A MODELING APPROACH FOR THE HOOP-COLUMN ANTENNA

Modeling studies of the "Maypole-cable-hoop-membrane" type antenna are being conducted using a transfer-matrix (ref. 8) numerical analysis approach. This methodology has been chosen as particularly well-suited for handling a large number of antenna configurations of a generic type. While not capable of providing, in principle, more information than a proper NASTRAN® formulation, a dedicated transfer matrix analysis, both by virtue of its specialization and the inherently easy compartmentalization of the formulation and numerical procedures, can be significantly more efficient not only in computer time required but, more importantly, in the time needed to review and interpret the results.

The analysis is seen as proceeding as follows: (1) state variable (bending, torsion, axial compression/tension) at the extremes of feed assembly and solar arrays will be "transferred" (by proper matrix transformations) inward; (2) wherever "branch points" occur (as at feed assembly to feed mast junctions, hoop support cable to upper mast assembly points, etc.), force and moment equilibrium and displacement compatibility conditions will be imposed, (3) the hoop-antenna-surface assembly will be modeled in pie-shaped segments, with transfers made azimuthally from one section to the next, and compatibility and equilibrium conditions imposed after state variables are transferred back onto themselves, that is, at 360^{o} of azimuth. Stiffness transfer matrices, for example along the mast and around hoop segments, will probably be modeled as equivalent beams using subsidiary finite-element analyses to establish the beam-equivalent quantities. Mass transfer matrices will probably be formulated on a "lumped parameter" basis, using a small enough breakdown to reveal local flexibility effects if they are significant and such often-neglected terms as rotational mass moment of inertia in beam-bending.

Advantage will be taken of the polar symmetry of the structure as a whole. That is, aximuthal solutions will be satisfied by Fourier series representation, as in many problems involving polar symmetry; the vibrations of circular plates (ref. 9, e.g.) is one such case when the boundary conditions are also polar symmetric. In the analysis we propose, natural frequencies and modes are pictured as solved as separate cases for each Fourier harmonic using an azimuthal fraction of the total antenna with the proper boundary conditions. For the η^{th} Fourier series term, $\cos \eta\theta$, only a π/η sector of the antenna would need to be considered, with the bending boundary conditions, for example, being transverse translation and bending moment equal to zero along the boundary of the pie-shaped element making up π/η sector of the full azimuth.

The numerical procedure for obtaining natural frequency and mode shape solutions would progress by trail and error, seeking values of ω that make an appropriate determinant zero. This would allow intermediate results (for a large number of particular values of trial frequency ω) for parts of the assembly (the mast, e.g.) to be stored for use in configurations with say, different antenna sizes if that's of interest, or different size solar arrays, and so forth. The numerical "assembly" of the various components in the transfer matrix approach can be held until the last steps of the numerical procedure, thus enhancing efficiency further, in studying a range of structures of a given generic type.

REFERENCES

1. Balas, M. J.: Toward a (More) Practical Control Theory for Distributed Parameter Systems. Control and Dynamic Systems: Theory and Applications, Volume 18, C. T. Leondes, ed., Academic Press, Inc., 1982. (To be published)

2. Kaufman, H.: and Berry P.: Adaptive Flight Control Using Optimal Linear Regulator Techniques. Automatica, vol. 12, no. 6, November 1976, pp. 565-576.

3. Desrochers, A. A.: On an Improved Model Reduction Technique for Nonlinear Systems. Automatica, vol. 17, no. 2, March 1981, pp. 407-409.

4. Balas, M. J.; and Lilly, J. H.: Adaptive Parameter Estimation of Large-Scale Systems by Reduced-Order Modeling. Proceedings of 20th IEEE Conference on Decision and Control, San Diego, CA, December 1981.

5. Balas, M. J.; and Johnson, C. R.: Adaptive Control of Distributed Parameter Systems: The Ultimate Reduced-Order Problem. Proceedings of 18th Conference on Decision and Control, Fort Lauderdale, Florida, December 1979.

6. Banks, H. T.: A Survey of Some Problems and Recent Results for Parameter Estimation and Optimal Control in Delay and Distributed Parameter Systems. Lefschetz Center for Dynamical Systems Report #81-19, Brown University, Providence, RI, July 1981.

7. Banks, H. T.; and Daniel, P. L.: Parameter Estimation of Nonlinear Nonautomous Distributed Systems. Proceedings of 20th IEEE Conference on Decision and Control, San Diego, CA, December 1981.

8. Pestel, E. C.; and Leckie, F. A.: Matrix Methods in Elastomechanics. McGraw-Hill Book Company, Inc., New York, 1963.

9. Leissa, A. W.: Vibration of Plates. NASA SP-160, 1969.