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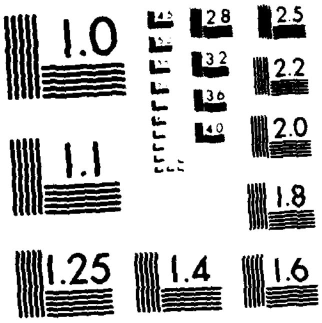

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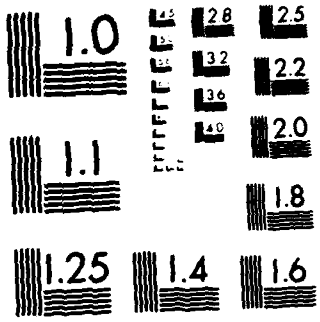

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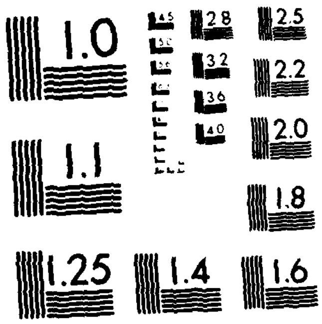

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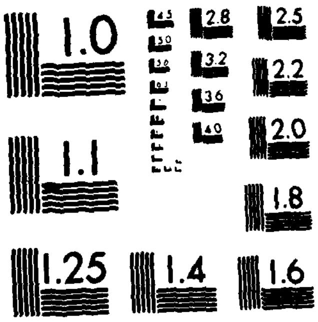

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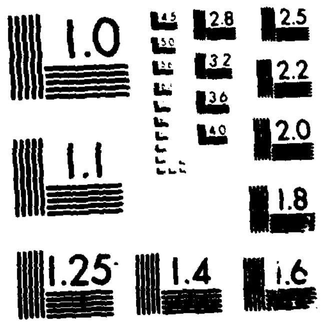

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ALGORITHMS FOR ESTIMATION IN DISTRIBUTED MODELS WITH APPLICATIONS TO LARGE SPACE STRUCTURES*+

by

H. T. Banks
Lefschetz Center for Dyanamical Systems
Division of Applied Mathematics
Brown University
Providence, Rhode Island 02912

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ALGORITHMS FOR ESTIMATION IN DISTRIBUTED MODELS
WITH APPLICATIONS TO LARGE SPACE STRUCTURES

H. T. Banks
Lefschetz Center for Dynamical Systems
Division of Applied Mathematics
Brown University
Providence, Rhode Island 02912

ABSTRACT

We discuss theoretical and computational results for spline based approximation schemes used in parameter estimation algorithms for distributed systems. Specific applications include beam-like structures described by the Euler-Bernoulli and Timoshenko theories and antenna surfaces such as that in the deployable Maypole Hoop/Column model.

INTRODUCTION

With the use of composite materials in large space structures and the exotic shapes and configurations for antennae, space stations, etc., the need for analysis with distributed system models to describe complex structures in changing environments has become evident. The expected fatigue, degradation, and changes in material properties due to ageing and environmental stress increase the importance of parameter and state estimation techniques for such models. We report here on our investigations of methods for parameter estimation. The ideas involve spline based approximation schemes to reduce the distributed system problem to approximate finite dimensional state system problems where existing algorithms can be employed. Our goals have been to guarantee convergence of our methods and to test their numerical feasibility. As we shall outline, the methods can be successfully used with both static and dynamic systems data.

DYNAMIC MODEL PARAMETER ESTIMATION

We present a brief summary of our joint efforts with J.M. Crowley (U.S. Air Force Academy) reported in more detail in [1], [2], [3]. We consider the following problem: In a dynamical model (e.g. Euler-Bernoulli or Timoshenko theories) for elastic structures, estimate parameters (such as flexural rigidity, shear rigidity, structural damping, loading, etc.) in the model from observations of the system.

Theory

For convergence results, we have developed a semigroup approximation framework for these higher order models that is related to that given for second order distributed systems in [4],[5]. A rather concise series of steps can be used to describe these efforts.

(i) We write the system (partial differential equation with boundary and initial data) to be investigated as an abstract evolution equation

$$(S) \qquad \dot{z}(t) = A(q)z(t)$$
$$z(0) = z_0$$

in an appropriately chosen Hilbert space. Here the operator A (and possibly the initial data z_0) depend on the vector of parameters q to be estimated, for example, by a least-squares fit to the observation data.

(ii) We choose approximation subspaces Z^N to Z and operators $A^N = P^N A P^N$, where P^N is the orthogonal projection of Z onto Z^N. This gives rise to an approximating system

$$(S_N) \qquad \dot{z}^N(t) = A^N(q)z^N(t)$$
$$z^N(0) = P^N z_0$$

in a finite dimensional space Z^N. (We have found it very profitable to use linear spans of spline basis elements - linear, cubic, quintic - for these subspaces.) An associated sequence $(N = 1,2,\ldots)$ of estimation problems for (S_N) is solved, yielding approximate parameter estimates $\bar{q}^N$.

(iii) A convergence theory for $\bar{q}^N \to \bar{q}$, $\bar{q}$ a solution of the estimation problem for (S), is obtained by employing general linear semigroup approximation results (the Trotter-Kato theorem) along with fundamental estimates on how Z^N and A^N approximate Z and A respectively (i.e. how (S_N) approximates (S)). (In our efforts these estimates are obtained from basic approximation theorems in spline analysis - e.g. [6],[7].)

We note that while most of our efforts in problems for elastic structures have dealt with estimation of constant parameters, our theoretical ideas (as well as the associated computational packages) are readily extended to treat problems with spatially varying coefficients. Our initial computational findings for these more difficult problems indicate that the resulting algorithms are very efficient.

Implementation

In practice we have used the spline approximation schemes with a standard package (IMSL-ZXSSQ) for the Levenberg-Marquardt finite dimensional optimization technique. The resulting algorithms have proved (as predicted by the theory) quite efficient in our program of extensive numerical testing. We have developed and tested algorithms based on quintic, cubic, and linear spline generated subspaces (the choices we used in each example depending to some extent on the particular system, the desired accuracy, and the amount of computational effort we were willing to expend).

In our testing of the algorithms we have focused on dynamic beam models. Our emphasis here has been largely motivated by the interest of engineers at NASA and elsewhere in the analysis of large complex structures through the use of equivalent simple continuum models (e.g. see [8],[9],[10]).

Examples

We have developed the theory and carried out numerical testing for a number of situations including the following.

(A) Viscoelastic models (the Euler-Bernoulli theory): Equations such as

$$m \frac{\partial^2 u}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(EI \frac{\partial^2 u}{\partial x^2} + cI \frac{\partial^3 u}{\partial x^2 \partial t}\right) + \gamma \frac{\partial u}{\partial t} = f$$

with various types of boundary conditions (combinations of fixed, simple and free) have been investigated and parameters such as $\frac{EI}{m}$ (flexural rigidity), $\frac{cI}{m}$ (structural damping), and $\frac{\gamma}{m}$ (viscous damping) have been successfully estimated. Schemes with quintic and cubic spline elements were employed.

(B) Models with shear and rotatory inertia (the Timoshenko theory): Equations studied include those for the transverse displacement y and angle ψ of cross sectional rotation

$$\frac{\partial^2 y}{\partial t^2} = \alpha\left(\frac{\partial^2 y}{\partial x^2} - \frac{\partial \psi}{\partial x}\right) + f$$

$$\frac{\partial^2 \psi}{\partial t^2} = \beta\left(\frac{\partial y}{\partial x} - \psi\right) + \gamma \frac{\partial^2 \psi}{\partial x^2}$$

with $\alpha = k'AG/m$, $\beta = \alpha A/I$, $\gamma = EA/m$ (E, G, I, k', A represent the usual Young's modulus, shear modulus, moment of inertia, shear coefficient, and cross sectional area respectively) among the parameters estimated. For a fixed end beam, cubic elements were employed while both cubic and linear element schemes were tested for the cantilever beam.

STATIC MODEL PARAMETER ESTIMATION

Our efforts on static estimation have involved at various stages joint efforts with P. Daniel (Southern Methodist University), E. Armstrong (NASA Langley), and R. Teglas (ICASE, NASA Langley). In this case the semigroup formulation for the theory underlying our algorithms is not needed. Instead we use a weak or variational equation formulation

$$\langle A_0(q)u-f,\ v\rangle = 0$$

of the equation of state in a Hilbert space. However the general steps (i)-(iii) outlined above in the dynamic case are again followed. In this case we also use spline subspaces (linear and cubic elements) for the approximations, combining standard spline theory estimates with variational inequalities to obtain the convergence theory of (iii).

In our implementation we have again used spline schemes with the Levenberg-Marquardt to generate and test our algorithms. We are presently still testing the methods on examples, but our initial computational findings are very promising.

Examples

We have developed the theory and are testing our algorithms on a distributed model for the antenna surface in the deployable Maypole Hoop/Column configuration under development by the Harris Corp. Our investigations have focused on the variational form state equation

$$\int_0^{2\pi}\int_{R_1}^{R_2} \{E\,\nabla u \cdot \nabla v - fv\}\,r\,dr\,d\theta = 0$$

where u is the vertical displacement (from hoop level $u=0$), $E = E(r,\theta)$ is the stiffness (elastic) coefficient, and f represents the applied distributed load (e.g. through the control stringers and catenary cord elements). In a simplified 1-dimensional test example (for which the convergence theory is rather easily obtained) where we assume angular symmetry, we have employed with success both cubic and linear element approximation schemes. Convergence results in the 2-dimensional model can be obtained but require somewhat more effort than in the 1-dimensional case. We are currently in the process of numerically testing the algorithms for this more general model.

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