Program

NSF-CBMS Regional Research Conference

Mathematical Control Theory of Coupled Systems of Partial Differential Equations

August 5-9, 1999, Lincoln, Nebraska

Principal Lecturer:
Professor Irena Lasiecka, University of Virginia

All numbered lectures given by Professor Lasiecka. All lectures are given in Bessey Auditorium.

Thursday, August 5

11am - noon: Lecture 1

1:30pm - 2pm: Mary Ann Horn, Uniform Stability and Asymptotic Behaviour with Respect to Thickness for a Cylindrical Shell

2pm - 2:30pm: George Avalos, Point Control and Observation of a Structural Acoustics Model

2:45pm - 3:45pm: Lecture 2

4pm - 5pm: Roberto Triggiani, Inverse Type Inequalities For Partial Differential Equations with Variable Coefficients

5pm - 5:30pm: Michael Demetriou, Optimal Location of Sensors and Actuators for Control of Acoustic and Structural Acoustic Models

Friday, August 6

10am - 11am: Lecture 3

11:15am - 11:45am: Marius Tucsnak, Optimal Location of the Actuator for the Pointwise Stabilization of a String

11:45am - 12:15am: Scott Hansen, Modeling and Control of Plates with Surface-Mounted Piezoelectric Actuators

1:30pm - 2:30pm: Lecture 4

2:45pm - 3:15pm: Marianna Shubov, Spectral Operators Generated by Damped Hyperbolic Equations and Their Applications to Control Problems

3:15pm - 3:45pm: Zhonghai Ding, Mathematical Modeling and Analysis of Thermoelectrical Heat Transfer Behavior of Shape MemoryAlloy Actuators

4:00pm - 4:30pm: David Yang Gao, General Analytic Solutions and Duality Theory for Nonconvex Variational/Boundary Value Problems with Applications in Dynamical Post-Bifurcation of Nonlinear Structures

Conference Banquet 6:30pm, Sheldon Gallery

Saturday, August 7

9:30am - 10:30am: Lecture 5

10:45am - 11:15am: Suzanne Lenhart, Optimal Control of the Obstacle for Variational Inequalities

11:15am - 11:45am: Richard Rebarber, Stability of the Active Wall Component of a Structural Acoustics Model

1:15pm - 2:15pm: Lecture 6

2:45pm - 3:15pm: Francesca Bucci, The Non-standard Finite Horizon LQ-problem for Boundary Control Systems

3:15 pm - 3:45pm: Renee Fister, Optimal Control of Harvesting Coupled with Boundary Control in a Predator-Prey System

4pm- 4:30pm: Zhuangyi Liu, Frequency Domain Characterization for Rational Decay Rate of Energy and its Applications

4:30pm - 5pm: MingQing Xiao, Center Manifold of a Nonlinear Partial Differential Equation that Models Compressor Systems

Concert 9pm

Sunday, August 8

9:30am - 10:30am: Lecture 7

10:45am - 11:15am: Catherine Lebiedzik, Uniform Stability in Structural Acoustic Models with Thermal Effects and Nonlinear Boundary Damping

11:15am - 11:45am: Hans Zwart, Stabilization of an Infinite-Dimensional System by a One Dimensional Control Operator

1:15pm - 2:15pm: Lecture 8

2:45pm - 3:15pm: Guangcao Ji, Adaptive Control of the Heat Equation

3:15pm - 3:45pm: Abdelaziz Soufyane, Uniform Stability of Coupled Second Order Equations

3:45pm - 4:15pm: Cheng-Zhong Xu, Eigenvalues and Eigenvectors of Infinite-Dimensional Closed-Loop Systems

Monday, August 9

10am - 11am: Lecture 9

11:15am - 11:45am: Ahmed Bader, Stability of Airflow Containing Dust and Application To Tornado Dynamics

11:45am - 12:15pm: Matthias Eller, Unique Continuation for Systems of PDE

1:45pm - 2:15pm: Eduardo Gallestey, Spectral Value Sets: Tool of Robustness Analysis

3pm - 4pm: Lecture 10

Abstracts

(These are listed in alphabetical order according to the last name of presenting author)

George Avalos
Department of Mathematics and Statistics
Texas Tech University

"Point Control and Observation of a Structural Acoustics Model"

We consider a controlled and observed partial differential equation (PDE) which describes a structural acoustics interaction, consisting of an acoustic chamber with a flexible chamber wall. The control is applied to this flexible wall, and the class of controls under consideration includes those generated by piezoceramic patches. The observation we consider is point measurements of acoustic pressure inside the cavity. Mathematically, the model consists of a wave equation coupled, through boundary trace terms, to a structurally damped plate (or beam) equation, and the point controls and observations for this system are modeled by highly unbounded operators. We analyze the map from the control to the observation, since the properties of this map are central to any control design which is based upon this observation. We also show that for an appropriate state space $\mathcal{X}$, if the initial state is in $\mathcal{X}$ and the control in L^2, then the state evolves continuously in $\mathcal{X}$ and the observation is in L^2. In the case that the geometry is a smooth bounded domain, the analysis of this system entails a microlocal analysis of the wave component, and the use of pseudodifferential machinery. For the canonical (but numerically important) case of the rectangle, a greatly simplified proof is provided by Fourier/harmonic analysis techniques, with this proof also exploiting the underlying analyticity of the beam component. Much of this is joint work with Irena Lasiecka and Richard Rebarber.

Ahmed Bader
Equipe de Mathmatiques de Besanon
Universit de Franche Comt- France

"On the Essential Spectrum of a Semigroup Generated by Hyperbolic Systems"

We are concerned with the asymptotic behavior of semigroup generated by mixed-initial value problems for hyperbolic systems in one space variable. We prove that the essential spectral radius of a semigroup generated by a hyperbolic system is the same as the one which correspond to a reduced system. The proof is based on decoupling techniques. We construct a reduced system (which is much simpler to study) such that the difference of semigroups is a compact operator. (This is joint work with F. Ammarkhodja)

Francesca Bucci
Dipartimento di Matematica Applicata
Universita' di Firenze

"The Non-standard Finite Horizon LQ-problem for Boundary Control Systems"

In this talk we give an account of recent results concerning optimal control with general quadratic cost functionals, for abstract linear systems with unbounded input operator. Special attention is devoted to an abstract class of systems which models a variety of hyperbolic (hyperbolic-like) Partial Differential Equations with boundary/point control. Necessary/sufficient conditions for finiteness of the value function of the control problem are discussed.

Michael A. Demetriou
Department of Mechanical Engineering
Worcester Polytechnic Institute

"Optimal Location of Sensors and Actuators for
Control of Acoustic and Structural Acoustic Models"

In this work we consider the problem of optimal location of actuators and sensors for optimizing performance in reducing the noise field in acoustic cavities and suppressing vibration in flexible structures. The control strategy is based on LQR/Hinf feedback control, and the optimization problem is formulated as minimizing the quadratic cost function which is averaged over the random initial conditions. The solution of the optimization problem requires solving matrix Riccati and/or Lyapunov equations. The effectiveness of the control strategy and its dependence on location of the sensors and actuators is demonstrated in several numerical examples. (This is joint work with F. Fahroo.)

Zhonghai Ding
Department of Mathematical Sciences
University of Nevada

"Mathematical Modeling and Analysis of Thermoelectrical Heat Transfer Behavior of Shape Memory Alloy Actuators"

Shape Memory Alloys have been proposed as actuators for shape and vibration control in many new engineering structures. In this talk, we discuss the mathematical modeling and analysis of the transient heat transfer behavior of thermoelectric shape memory alloy (SMA) actuators. We will present some results in a recent joint paper by Z. Ding and D. Lagoudas. For the transient heat transfer with a constant current density, it is proved that there is an upper bound for the current density so that the temperature distribution along the SMA layer is stable. For the transient cooling problem with a constant current density, it is proved that there is a lower bound for the current density so that the temperature at the interface between SMA and semiconductor layers is always decreasing to its stable state, and it may not be always decreasing if the current density is below the lower bound. Estimates for these bounds are derived. The physical implications of the main results are also discussed.

Matthias Eller
Tennessee Technological University
Cookeville, TN

"Unique Continuation for Systems of PDE"

Theorems on unique continuation for solutions to partial differential equations are crucial for obtaining results on boundary controllability for partial differential equations. The unique continuation problem can be formulated as follows. Considering a solution to a homogeneous partial differential equation in a bounded domain with zero Cauchy data on part of the boundary, can one conclude that the solution vanishes in the domain?

The classical results on unique continuation are Holmgren's theorem and Hörmander's theorem. Holmgren's theorem requires analytic coefficients of the differential operator. That makes it impractical for many applications. On the other hand, Hörmander's theorem is valid only for scalar equations and its results are optimal only for second order equations. The proof of this theorem is based on a certain type of weighted energy estimate which was introduced by Carleman. These estimates have led recently to uniqueness results for higher order equations and for systems of partial differential equations.

In 1995, Tataru published a new result on unique continuation interpolating between Holmgren's and Hörmander's theorem. His result allows us to prove sharp uniqueness results for equations with time independent coefficients. These equations often arise in applications. Moreover, Tataru's result can be extended to some systems and higher order

equations. We will present new uniqueness results for the Kirchhoff plate equation and a thermo-elastic system.

K. Renee Fister
Department of Mathematics and Statistics
Murray State University

"Optimal Control of Harvesting Coupled with Boundary Control in a Predator-Prey System"

We consider boundary control and control via harvesting in a parabolic predator-prey system for a bounded region. The boundary control depicts the relationship between the boundary environment and the possibly harmful species. In addition, a proportion of the other species is harvested for profit. We choose to maximize the objective functional which incorporates the size of one species and the revenue of harvesting of the other less the economic cost of sustaining a satisfactory boundary habitat and the cost due to the harvesting component. Moreover, we characterize the unique optimal control in terms of the solution to the optimality system, which is the state system coupled with the adjoint system.

Eduardo Gallestey
Department of Engineering
Australian National University

"Spectral Value Sets: Tool of Robustness Analysis"

Spectral value sets (SVS) are subsets of the complex plane, which are useful in studying the sensitivity of eigenvalues, possible effects of uncertain parameters on the spectrum and questions of robust stability. In the finite dimensional case, these sets have been defined and characterized for structured real and complex perturbations by Hinrichsen and Kelb. Furthermore, SVS are related to the notion of pseudospectra, a tool of matrix analysis that has been popularized by Trefethen and Godunov in recent years. Spectral value sets can be also defined and characterized for infinite dimensional systems. The key quantity for the analysis is the norm of certain transfer function.

The talk is an introduction to the matter. First we develop some intuition on spectral value sets with the help of examples. Then, we give a formal definition, some of their properties and discuss an algorithm for their reliable computation. Finally, we apply our results to the robustness analysis of delay operators.

David Yang Gao
Department of Mathematics
Virginia Tech

"General Analytic Solutions and Duality Theory for Nonconvex Variational/Boundary Value Problems with Applications in Dynamical Post-Bifurcation of Nonlinear Structures"

The speaker will present a newly developed, potentially powerful sequential canonic dual transformation method, by which many nonconvex variational/boundary value problems in mathematical physics and nonlinear structural mechanics can be solved completely, including some classical differential geometry problems.

It is known that partial differential equations in finite deformation theory are usually fully nonlinear (i.e. both geometrically and constitutively nonlinear). In phase transitions and hysteresis, post-bifurcation of nonlinear structures, elastoplastic flow with harderning and jumping effects, etc, the total potential energies are generally nonconvex and nonsmooth. Also, in nonconvex dynamical systems, the problems are extremely sensitive to the initial data and physical parameters. Different algorithms and numerical methods may produce the so-called chaotic "solutions". Without comparison with dual bounds, we really can not say which numerical result produced by one-side direct method is more precise.

While we see the intrinsic difficulties in traditional analysis and direct methods, we will take the opposite approach. Based on the general duality theory in nonconvex/nonsmooth analysis developed by the speaker recently, a general method for establishing the right dual variational principle (without duality gap) will be presented. By using this method, many fully nonlinear partial differential systems in certain nonconvex/nonsmooth variational problems can be converted to certain dual algebraic (tensor) systems, and therefore, a general closed form solution is obtained. The uniqueness, stability and extremality conditions of this general solution are fully clarified by an interesting triality theory. The connection between nonlinear partial differential equations and algebraic geometry is revealed.

Applications are illustrated by examples in phase transitions with multi-well energy, elastoplastic post-bifurcation with jumping and harderning effects and nonconvex dynamical systems. Some very interesting new intrinsic phenomena in Duffing type systems will be shown by a dynamical buckling beam model.

Scott Hansen
Department of Mathematics
Iowa State University

"Modeling and Control of Plates with Surface-Mounted Piezoelectric Actuators"

First, several possible models for a piezoelectric plate are discussed. We then consider the model that results from bonding a piezoelectric plate to a portion of the surface of a plate. In the approach discussed, unlike the common engineering theories, the electrical coupling is retained, rather than eliminated through a stress-free approximation. One advantages to this approach is that proper boundary conditions are easily obtained through the variational method. In addition one is within a framework in which regularity issues are easily studied.

Mary Ann Horn
Department of Mathematics
Vanderbilt University

"Uniform Stability and Asymptotic Behaviour with
Respect to Thickness for a Cylindrical Shell"

Uniform stabilization of a cylindrical shell through the use of boundary feedback control is discussed. At issue is the question of whether stabilization is robust in the limit as the thickness of the shell tends to zero. To establish an affirmative answer to this question, the effect of the thickness must be tracked throughout the estimates required to prove uniform stabilization. Our approach is based on the multiplier method; however, the desire to track the thickness requires the use of sharp trace regularity estimates as well as unique continuation results for the cylindrical shell model. Proof of sharp trace regularity is achieved by taking advantage of microlocal analysis. Unique continuation is derived through the use of Carleman estimates. (This is joint work with C. McMillan)

Guangcao Ji
Department of Mathematics and Statistics
Texas Tech University

"Adaptive Control of the Heat Equation"

We consider the heat equation with an unknown parameter in a smooth domain. An adaptive feedback law is designed such that the output of the closed loop system tracks, asymptotically, the the output of a given reference model. The closed-loop system is a nonlinear integral-differential equation. It is proved that the tracking error approaches zero in various norms as time goes to infinity.

Catherine Lebiedzik
Institute of Applied Mathematics and Mechanics
University of Virginia, Charlottesville

"Uniform Stability in Structural Acoustic Models
with Thermal Effects and Nonlinear Boundary Damping"

We are interested in a coupled PDE system arising in problems dealing with the active control of structural acoustic systems. An acoustic chamber is surrounded by an active plate or wall, and the pressure in the chamber is controlled via piezoceramic actuators. We consider a model that includes thermal effects and dispenses with the need for any type of damping (including structural) acting upon the active wall (interface between the two media). This is in contrast with all the literature available on the topic. Our main result is the uniform stabilization of the system as a consequence of thermal effects.

Suzanne Lenhart
Department of Mathematics
University of Tennessee

"Optimal Control of the Obstacle for Variational Inequalities"

An optimal control problem for a parabolic obstacle variational inequality will be discussed. The obstacle is taken to be the control and the solution of the obstacle problem is taken to be the state, with the objective of achieving a state close to the desired profile taking into account the cost of the control. Existence of an optimal control will be presented. A corresponding elliptic problem will also be included.

Zhuangyi Liu
Department of Mathematics and Statistics
University of Minnesota - Duluth

"Frequency Domain Characterization for Rational
Decay Rate of Energy and its Applications"

Richard Rebarber
Department of Mathematics and Statistics
University of Nebraska - Lincoln

"Stability of the Active Wall Component of a Structural Acoustics Model"

We consider an oft-studied model for structure/acoustics interactions. In this model the displacement of the active boundary Γ_0 of the acoustic cavity is modeled by a Kelvin-Voigt damped beam equation, and the acoustic pressure is modeled by a two-dimensional wave equation. Avalos and Lasiecka have shown that this model is strongly stable but not exponentially stable. They have also shown that the beam velocity and displacement are in $L^2[0,T;H^2(\Gamma_0)]$ for any $T > 0$, any appropriate initial conditions and any L^2-control. We show that when the inital conditions for the wave component are zero, then the beam velocity and displacement are in fact in $L^2[0,\infty;H^2(\Gamma_0)]$.

The approach used to prove this stability result is novel in the sense that frequency domain analysis is the primary tool. As a corollary we see that a very large class of dynamic controllers cannot exponentially stabilize the structural acoustics model if the controller input only contains measurements on the beam.

Marianna A. Shubov
Department of Mathematics and Statistics
Texas Tech University

"Spectral Operators Generated by Damped Hyperbolic Equations
and Their Applications to Control Problems"

A review of the results by the author on the asymptotic and spectral analysis of several classes of nonselfadjoint operators in a Hilbert space will be presented. These operators are the generators of the strongly continuous semigroups defined by several hyperbolic equations and systems containing viscous damping terms and subject to dissipative boundary conditions. The list of those systems, which appear in the theory of vibrating elastic structures, includes: a) the equation of a spatially nonhomogeneous damped string; b) the hyperbolic system which governs the Timoshenko beam model (the most physically realistic model of a thick beam having important applications in struc- tural engineering); c) the system which governs coupled Timoshenko and Euler-Bernoulli beams; d) 3-dimensional spacially nonhomogeneous spherically symmetric damped wave equation. The review will also include the spectral asymptotic results for a system of integro-differential equations containing hysteresis terms, which models an aircraft wing in a subsonic air flow. Preliminary results on the spectral analysis of the dynamics generator for a 3-dimensional nonspherically symmetric spatially non-homogeneous damped wave equation will be discussed.

Abdelaziz Soufyane
Department of Mathematics
Franche-Comte University in France

"Uniform Stability of Coupled Second Order Equations"

I will present in this talk some results about controllability and uniform stability of second order coupled equations. I present sufficient conditions for uniform stability of such systems. Finally we give an result of the stabilization of Timoshenko beam by using one control force. (This work is joint with Assia Benabdallah)

Roberto Triggiani
Department of Applied Mathematics
University of Virginia

"Inverse Type Inequalities For Partial Differential Equations with Variable Coefficients"

We consider (mutidimensional) second-order hyperbolic equations as well as other dynamics such as Schrodinger equations, with variable coefficients in the principal part as well as in the energy level terms. Low regularity of the coefficients is assumed. The talk is divided in two parts.

1) For the above equations, we obtain a-priori inverse type Carleman estimates, at various energy levels, by means of Riemann geometric methods, under sharp, often checkable conditions. As a corollary, one obtains continuous observability inequalities, modulo interior lower order terms, with explicit, possibly optimal time, as well as corresponding uniform stabilization estimates in the case of appropriate dissipative terms. Lower order terms can then be absorbed under global uniqueness results of the corresponding overdetermined problem.

2) On a related and in fact complementary side, we obtain Carleman estimates for second order hyperbolic equations in the purely Neumann case, by using a more flexible approach, at least when the principal part is the Laplacian. Hence continuous observability inequalities without interior order terms follow. A fortiori, we obtain new global uniqueness results for the corresponding overdetermined hyperbolic problem.

Marius Tucsnak
Institut Elie Cartan
Université de Nancy I

"Optimal Location of the Actuator for the Pointwise Stabilization of a String"

We study the large time behavior of the solutions of a homogenous string equation with a homogenous Dirichlet boundary condition at the left end and a homogenous Neuman boundary condition at the right end. A pointwise interior actuator gives a linear viscous damping term. We give a complete characterization of the positions of the actuator for which the system becomes exponentially stable in the energy space. Moreover we show that the fastest decay rate is obtained if the actuator is located at the middle of the string.

MingQing Xiao
Department of Mathematics
University of California - Davis

"Center Manifold of a Nonlinear Partial Differential Equation that Models Compressor Systems"

A commonly used mathematical model that captures the flow behavior of a compression system, due to Moore and Greitzer, consists of a PDE and two ODEs. The PDE describes the behavior of disturbances in the inlet region of compression system, and the two ODEs describe the coupling of the disturbances with the mean flow.

In this talk it will be shown that the PDE system features a local center manifold. The significance of this result is that a study of the behavior of the local flow in the compressor can thus be translated into a study of the flow of two scalar differential equations on the center manifold. The result is obtained by converting the original PDE system into an evolution equation on a Hilbert space, and showing that this equation and its linearized version (around a desired equilibrium) are not topologically equivalent. The stability of the flow will be discussed through the reduced two dimensional system.

The talk will conclude with a discussion of some control issues that arise in the stabilization of the flow through compressor systems, and some underlying mathematical challenges.

Cheng-Zhong Xu
Inria Conge
Bât. A, Université de Metz

"Eigenvalues and Eigenvectors of Infinite-Dimensional Closed-Loop Systems"

We consider unit output feedback control of infinite-dimensional well-posed linear systems. The aim of our work is to investigate the relationship between the eigenvalues of the open-loop system and the controlled system, and to give a useful characterization of the eigenvalues of the controlled system in terms of the available data on the open-loop system. Especially, we are interested to know when the eigenvectors of the closed-loop system form a Riesz basis and we obtain some results in this direction.

We illustrate the usefulness of our results through several examples in the stabilization of systems described by partial differential equations. For these systems we show that the sequence of generalized eigenvectors of the closed-loop system form a Riesz basis in the state space. Our approach leads to a unified treatement for different cases which have been studied separately in the literature. Our approach enables us to simplify or avoid long computations which were necessary otherwise. The exact controllability (or exact observability) needed to be verified in our approach can be tested by a powerful method such as the multiplier method.

Hans Zwart
Department of Applied Mathematics
University of Twente, The Netherlands

"Stabilization of an Infinite-Dimensional System by a One Dimensional Control Operator"

Suppose that a system is given as the following abstract differential equation

$$\dot{z}(t) = Az(t) + bu(t), z(0) = z_0,$$

where A generates a strongly continuous semigroup on the Hilbert space Z. On b we make no smoothness assumption (yet); we only assume that b is a vector in some Hilbert space. By stabilization of the above system we mean that for any $z_0 \in Z$ there exists a input, $u(\cdot)$, such that $z(t)$ goes to zero exponentially. We shall show that even this general definition of stabilizatity gives conditions on A. For instance, in the closed right half plane the spectrum of A consists of only point spectrum.

This lecture is meant as an overview of results obtained with Ricahrd Rebarber and Birgit Jacob.

Participants

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