MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 10/1987

Mathematics in Industry

1.3. bis 7.3.1987

Naturgemäß lassen sich die auf dieser Tagung behandelten Themen nicht unter einigen wenigen Überschriften zusammenfassen. Im Gegenteil war ein Ziel die Demonstration der Breite industrieller Anwendungen verschiedenster mathematischer Techniken. Neben dieser, das Generalistentum fördernden, Tatsache wurde aber auch verdeutlicht, daß sich häufig in der industriellen Praxis überraschende Anwendungsgebiete für "reine" bzw. "abstrakte" Bereiche der Mathematik ergeben. Im Folgenden soll eine kurze Übersicht über die in 28 Vorträgen und vielen informellen Diskussionen behandelten Themen gegeben werden.

Ein Hauptgewicht lag bei der mathematischen Modellbildung mit Beispielen aus der chemischen Industrie, der Epidemologie, Umweltuntersuchungen, der Halbleiterindustrie, der optoelektronischen Signalübertragung und der Off-Shore Montage. Ein weiterer Schwerpunkt lag im Bereich der Numerik (Simulation von Vorgängen in der Prozessindustrie unter Verwendung von Methoden zur Lösung von Differentialgleichungen auf Graphen, Interpolations- und Konversionstechniken im Bereich des CAD, Einsatz von Reifenmodellen auf dem Computer zur Vermeidung mechanischer Tests) und der Systemtheorie (Filterung, Identifikation, Anwendung der Differentialalgebra in der Kontrolltheorie). Behandelt wurden ferner Optimierungsfragen in der Stahlindustrie, stochastische Methoden beim Entwurf von Produktionssystemen und der Beschreibung von Schaltnetzwerken, mathematische Methoden bei der Signal- und Datenverarbeitung und die Entwicklung neuer Filtertechniken in der Bildverarbeitung. Als Abschluß seien genannt die Beschreibung von chaotischen Phänomenen in Getrieben, Eigenwertaufgaben im Ingenieurwesen und die Analyse der Wellengleichung zur Ausregelung von Oszillationen (Anwendung in der Raumfahrttechnologie). Das letztgenannte Thema und die oben erwähnte Filterungsproblematik in der Systemtheorie lieferten besonders eindrucksvolle Beispiele für die in der Einleitung angesprochene Anwendbarkeit "abstrakter" Mathematik in der industriellen Praxis.
Hervorzuheben ist noch eine gemeinsame Veranstaltung mit der zur gleichen Zeit stattfindenden Tagung über "New Foundations in Set Theory".
Die Leitung der Tagung lag in den Händen von Prof. Dr. H. Neunzert (Kaiserslautern).

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V o r t r a g s a u s z ü g e

S. HOWISON:

The Use of Complex Variables in Industrial Problems

The powerful techniques of complex analysis have always been central to much applied mathematics. Here we give 2 examples of their use in industrial problems to obtain valuable qualitative and quantitative information about their solutions. The 1st example is a film coating process in which a cylindrical wire is coated by drawing it vertically through a viscous liquid. Far upstream the flow is 2-dimensional, with gravity balancing viscosity and we give an analysis of the film shape near a sharp corner where the coating is likely to be thin; we show that its thickness is reduced by a factor $2/\pi$. The second example concerns heat and current flow in a thermistor, a circuit device made of a material whose resistivity increases by several orders of magnitude as its temperature (driven by Joule heating) passes through a critical value. We use a conformal mapping argument to show that in the steady state the "hot region" of high resistivity must be thin.

U. ECKHARDT
(joint work with G. MADERLECHNER)

Projections of the Radontransform - Applications in Picture Processing

P. V. C. Houg observed in 1962 that in the Radon transform of a binary picture the maxima correspond to lines in the original picture. Thus this transform became very attractive in document processing. In order to reduce the computational effort when searching for maxima in the transformed image, it is projected with respect to one variable. It can be shown that a linear projection which is invariant with respect to a certain class of linear transformations will yield useless results. Thus, in order to get practically relevant results of the projection one either has to introduce a nonlinear projector or a nonlinear filter function or else to use a non translation invariant operator. Some consequences of these results are discussed.

W. SCHEMPP

The Coupling of Lasers/Fibers and Lasers/Lasers

The lecture deals with a mathematical model of laser-optoelectronics. The model is based on the notion of ambiguity function and describes optical fiber waveguides as well as buried heterostructure semiconductor injection laser diodes (BH-ILDs). It is used to calculate by overlap integrals the coaxial couplings

laser/fiber

and

laser/laser

which are important in the field of optical communication systems. Moreover, a two-stage scheme is sketched to adapt the model to actual opto-couplers.

F. JONDRAL

Mathematical Methods in the Analysis of High Frequency Signals

The present contribution sketches some methods used for the analysis of high frequency signals. High frequency signal analysis is either done by the help of a manually tuned single channel receiver or by using a multichannel filter bank. The signal detection, which is in case of the multichannel approach a component of the band segmentation unit, performs a measurement of the energy distribution over the whole high frequency band.

A segmentation procedure decomposes the band into separate receiver channels. In each of these channels a signal classifier can determine the modulation mode by which the information was stamped on the carrier frequency by the corresponding transmitter automatically. After signal classification the signals may be postprocessed and demodulated in an optimal manner.

R.M.M. MATTHEIJ

On a Pipe Laying Problem

The problem we consider arises from questions dealing with the laying of pipes offshore. If the characteristic weight of the pipe is not negligable (as for gas pipes) and the depth of the sea bottom is fairly large the beam equation is highly nonlinear. A particular question is to determine the shape of

the pipe attached to a stinger (of a lay barge) at one end and resting on the sea bottom on the other end. There is a known horizontal force and an unknown vertical (bottom reaction) force exerted on the pipe. Numerical calculations are very hard if no fairly accurate estimate can be given.
We shall investigate the analytical problem to understand why this is so. To this end we examine a generalized Kirchhoff pendulum and show that a multitude of solutions may exist close to the wanted shape of the pipe.

P. TEIGEN

Some Mathematical Problems Related to Offshore Installation Operations

The background for the presentation is a practical problem of considerable interest in deep water offshore application: The precision installation of an object on the sea floor with the assistance of one or more surface vessels. The mathematical modelling of this situation gives rise to several related mathematical problems, some of which may be treated rather successfully by mathematical techniques.

G. STOYAN

Differential Equations on Graphs: Modelling of Transport, Mixing and Reactions in Systems of Tubes

Considered are equations of parabolic type which may degenerate to hyperbolic equations. For their numerical solution, a difference scheme is developed continuously connecting well - approved approximations of the parabolic and hyperbolic case, including the method of characteristics (which is decisive for suppression of numerical diffusion).
The motivation was originally an environment protection problem (computation of concentrations in systems of rivers, channels and lakes); now a program package is being developped for simulation of processes in industrial tube systems.

P.F. HODNETT

Wave Induced Washout of Submerged Vegetation in Irish Lakes

The Irish Central Fisheries Board which is responsible for monitoring and maintaining fish stocks in Irish lakes, has noted that at times vegetation growing on lake bottoms is washed away by the action of the wind on the lake surface. Since the vegetation is necessary for the health and survival of fish stocks they wish to prevent vegetation washout but to do so, it is necessary to understand the mechanism through which it occurs. They, therefore, wish to establish a model which can predict washout for given wind speed, wind direction and lake geometry. To achieve this, it is necessary to understand how the action of wind driven waves on the surface of the lake is transmitted down to the lake bottom to create bottom stresses which cause washout of vegetation from the lake bottom. The talk will outline attempts to create such a predictive model for submerged vegetation washout.

H.W. ENGL

A Mathematical Model for the Production Line "Steelmaking Continuous Casting, Hot Rolling"

We present a mathematical model for the problem, in which order a given "product-mix" consisting of steel slabs of different widths should be produced in the production line "steel-making, continous casting, hot rolling". There are many restrictions, especially due to the fact that because of the wear of the rolls, the sequence of widths is not arbitrary.
The resulting optimization problem has some strange features. We discuss an algorithm which we are currently testing for this problem.
As a subproblem, the question arises how to adjust secondary cooling in the continuous casting process in such a way that for different casting speeds, the same solidification front arises. We report about the implementation of an algorithm achieving this and about some mathematical results. (Joint work with G. Landl and T. Langthaler, Linz).

H. GFRERER

Optimal Control for Reheating of Slabs

In steelprocessing reheating of slabs is rather energy consuming. In this talk we want to present a model for optimal control of the reheating process such that the energy necessary to fulfill all technical restrictions should be a minimum.

S. A. HALVORSEN

Dynamic Model of a Metallurgical Shaft Reactor with Irreversible Chemical Kinetics and Moving Lower Boundary

A (preliminary) unidimensional dynamic model for simulating a metallurgical reactor has been implemented. A system of nonlinear hyperbolic differential equations describes a shaft reactor with gas reacting in countercurrent with solid/liquids. Due to irreversible chemical kinetics the first derivative of the reaction rates will be discontinuous. The lower shaft boundary can be moving.

Application of control volume spatial discretization and a suitable (standard) time integration routine for (stiff) ordinary differential equations, has proven successful for the gas flow/heat transfer problem. The approach does not work "as is" when including irreversible, fast gas reactions. Some method for stabilizing the gas variables is necessary.

If the model incorporates control volumes that can approach zero volume, Newton type methods are unsuitable for solving the nonlinear equations involved.

K. MERTEN

Mathematical Problems in the Computer Aided Design of VLSI Integrated Circuits

This lecture gives an overview about design methods, various design steps and related mathematical problems. In particular some typical problems, are discussed in detail:

For the well known placement problem existing (and running!) solutions are presented. A new approach with help of a new exact mathematical model is introduced.
A new systematic description of the delay time calculation problem was presented. As result we can show how to calculate straightforward sharp lower and upper bounds for the exact solution.
Actually the industry is especially asking for better solutions for circuit simulation (analog simulation). An overview about related numerical problems and advanced solutions achieved so far in our CAD-group is given. Finally system specific questions for a low level simulation system (Process, Device, Circuit) in an industrial environment are discussed.

M. FLIESS

Differential Algebra: A New Tool in Non-linear Control Theory

It is shown how differential algebra can be employed for solving some long standing problems of nonlinear control theory, like, for example, the input-output inversion problem which was open since more than twenty five years. The possibility of practical implementations of these techniques is briefly discussed.

F.-J. PFREUNDT

Identification of Nonlinear Deterministic Dynamical Systems

Two industrial applications of Numerical Identification are used to show what kind of problems should be attacked by identification and how a proposed new nonlinear identification procedure can improve the results.
The applications are computersimulations of a car including the tires and the simulations of the water temperature in a swimming pool.The proposed nonlinear identification procedure is based on Guidorzis linear identification algorithm and can identify nonlinear dynamical systems of the following kind:

$$x_{t+1} = Ax_t + Bu_t + \sum_{l=1}^{p} D_e\, x_t^{[l]} \qquad y_t = Cx_t$$

where the nonlinearities occur only in those state components which could be directly observed from the output.

P. RENTROP
(joint work with U. WEVER)

Interpolation Algorithms for the Control of a Sewing-Machine

In future industrial applications a sewing pattern characterized by typical points shall be designed at a screen. An interpolation algorithm, which works as a black box for the designer, shall generate an interpolating curve. Using the transformation between the coordinates of the screen and the transport mechanism of the sewing machine, the method shall compute the coordinates of the needle position. The complexity of the proposed method must be small enough, that the method can be realized on a Personal Computer with an 8 Bit CPU. In our report we discuss the performance of several interpolation algorithms for given examples. The tested algorithms are divided into two classes: <u>local</u> procedures like the Fritsch-Carlson scheme or the quadratic splines and global procedures like cubic splines or exponential splines.

J. HOSCHEK

Approximate Conversion of Spline Curves

In German car body industries (VDA) the different manufacturer and their subcontractors have different geometric modelling systems for curve and surface representation. For exchanging data between different systems approximate conversions of spline curves are required. Conversion means reducing the degree of a spline curve (and splitting more than one segment) or elevating the degree of more than one spline segment (and merging to one segment). The main tool is the use of parameter optimization and nonlinear optimization techniques in combination with the Bèzier technique.

M. PRIMICERIO

Dynamics of "Slurries"

A work in progress is reported concerning mathematical models for concentrated stable suspensions of coal particles in water ("slurries").
The rheological behaviour of this fluid is rather complicated: experiments show that a "pseudoviscous" relationship between the stress and the shear rate is satisfied $\tau = K\,\dot{\gamma}^n$ where K and n are to be determined experimentally.
The proposed model assumes that K evolves following a law according to which the fluid deteriorates - i.e. the viscosity increases - because of the energy which is dissipated in it.

In a particular one-dimensional model problem on has

$$v_t = (K\, v_x)_x \qquad \text{(n has been taken = 1)}$$

$$K_t = \varkappa\, v_x^2$$

plus suitable initial and boundary conditions.
The well-posedness of the problem can be proved and a numerical scheme proves to work.

H. WACKER

Steady State Determination in Chemical Plants

Chemical plants consists of units (plates, distillation/absorption columns with pumparounds and sidestrippers, reactors, heatexchangers etc.) and connecting streams. To determine the steady state (thermodynamic equilibrium) we propose a 3-phase algorithm: (i) determination of irreducible cycles and the connecting streams to be torn, estimations of the input streams, (ii) determination of the steady state of all the subsystems with given input, (iii) continuity condition for the streams by help of a fixed point equation.
The mathematical model e.g. for an extended multicomponent (M) multistage (N) plate involves mass bilances, enthalpy balances and equilibrium conditions resulting in a nonlinear system in (2M+1)N variables at least. The proposed hybrid technique is demonstrated by help of examples and compared to existing algorithms.
Work has been performed in cooperation with Voest, Austria

J. WESSELS

Design of Production Networks

The design of complex production lines or networks is usually based on simulation studies. It would have advantages if analytical tools were available to complement simulation. There are attempts in two directions: queueing and fluid approximation. In the present talk the idea of fluid approximation is outlined and it is illustrated with a practical case.
The idea essentially applies the theory of regenerative processes and originates from Wyngaard (AIIE-Trans. 1979). The practical case is treated via decomposition. This is joint work with De Koster, Zym and Hontelen.

T. HANSCHKE

Charaterization of Antidominant Solutions of Differential Equations with Applications in Queueing Theory

The contribution deals with a certain class of nonhomogeneous quasi-birth-and-death processes. Such processes arise from stochastic models for switching networks and tandem queues with state-dependent service rates. It is seen that the partial generating functions of their steady state probabilities can be represented as a solution of a singular linear system of differential equations. Using stochastic arguments it can be shown that there is only one solution being analytic inside the open unit disk. In order to compute the moments of the queueing processes it is necessary to determine the initial values of that solution at z = 1. The method employed can be interpreted as a generalization of so-called Jacobi-Perron algorithm.

L. STREIT

Chaos in Gearboxes

Rattling in gearboxes is discussed in terms of dissipative maps. In particular the technically desirable regime of wide spectrum wise generation is related to the occurence of chaotic attractors. It is indicated that a probabilistic Fokker-Planck treatment of the phase space density is very effective, at least in the "chaotic" parameter range.

V. CAPASSO

A Reaction-Diffusion System Modelling the Spread of a Class of Infectious Diseases

The present talk is a report of a joint work with V. Arnautu and V. Barbu (Iasi-Romania); K. Kunisch (Graz-Austria) and H. Thieme (Heidelberg-F.R.G.) in the context of the special program "Control of Infectious Diseases"of the CNR of Italy.
A reaction-diffusion system comprising a linear parabolic equation and a nonlinear ordinary differential equation has been used to model the spread of infectious diseases of man-environment-man type such as infectious hepatitis, typhoid fever, etc. The coupling of the first equation to the second one occurs via an integral boundary feedback. This particular coupling mechanism applies to habitants along the sea shore where sewage is usually sent untreated to the sea. The same kind of model can anyhow be applied to a wider class of reaction-diffusion systems such as chemical reactions between a gaseous and a solid reactant.
Existence, uniqueness and regularity of the solutions have been discussed. A threshold theorem has been proven giving necessary and sufficient conditions for the stability of the trivial equilibrium solution.
Problems of identification of parameters and states have also been discussed.
An optimal control problem has been treated in which the cost function opposes the cost of the epidemic to the cost of sewage treatment systems.

K. SCHILLING

Processing of Satellite Data - The Scatterometer

For up-to-date mesoscale weather forecasts the quick processing of satellite raw data is of major importance. In the case of satellite-borne scatterometers, e.g. ERS-1 and NROSS, a triplet of backscatter coefficients is generated for every measurement point. These data are correlated with wind speed and wind direction through an empirical model. To extract the wind data from the measurements a nonlinear least squares problem with up to 4 solutions must be solved. Here a two-stage approach is proposed to compute all possible solutions very quickly. The structure of the model is exploted to generate good estimates of the solutions by Newton's method, which are used as starting points for the Levenberg-Marquardt-algorithm to solve the least squares problem. This problem-adapted method seems to offer advantages with respect to computation time.

The further data processing to generate typical wind-maps will be studied, including problems like projections onto maps, variations of the resolving power, global wind analysis.

M. HAZEWINKEL

Filtering

Consider a system $dx = f(x)dt + g(x)\,dw$, $dy = h(x)\,dt + dv$, $x\in\mathbb{R}^n$, $y\in\mathbb{R}^p$, $w,v\in\mathbb{R}^m$ independent Wiener noise processes. I.e. we have an ODE subject to statedependent random disturbances and the available observations are given by $y\in\mathbb{R}^p$ and are corrupted by further independent noise. The filtering problem now consists of finding suitable calculation procedures for

$$\hat{\phi}(x) = E\,[\phi(x)\,|\,y_s,\ 0\leq s\leq t],$$

the conditional expectation of $\phi(x)$ given the observations y_s, $0\leq s\leq t$. The Kalmanfilter for $\hat{x}$ in a linear system

$$dx = Ax + Bdw,\ dy = Cxdt + dv\ \text{(known A,B,C)}$$

is an example of such a filter. Such problems occur very frequently and identification can be regarded as a (nonlinear) filtering problem. An exact finite dimensional recursive filter for $\hat{\phi}(x)$ is a machine

$$dm = \alpha(m)dt + \sum\beta_i(m)dy_{it},\ \gamma(m) = \hat{\phi}(x).$$

There is always an infinite dimensional recursive filter given by the socalled DMZ equation

$$d\rho = L\rho dt + \sum h_i\rho dy_{it},$$

when L is a semielliptic differential operator explicitly given in terms of f,g,h. Then

$$\hat{\Phi}(x) = \int \Phi(x)\rho(x,t)dx \;/\; \int \rho(x,t)dx$$

($\rho(x,t)$ is an unnormalized version of the density $\hat{\rho}(x,t)$ of $\hat{x}(t)$). The estimation Lie algebra is defined as the Lie algebra generated by L and the multiplication operators h_i. The DMZ equation is bilinear and if it is topologically solvable an infinite version of Wei-Namur theory can be developed leading to asymptotic expansion for $\rho(x,t)$. This applies in many cases and can always been made to apply by a "discounting large observations" trick. There is positive experimental evidence that these expansions work well and theoretical grounds to believe that a version of renormalization theory will yield further results.

C. BARDOS

Application of Propagation of Singularities to Control Theory

This talk is a report on a joint work in progress with G. Lebeau and J. Rauch. The problem is the stabilisation of a large scale structure which oscillates according to the linear wave equation. The control action is distributed on a part of the boundary Σ and active during a time T. We have shown that to obtain for every solution an exact control or an exponential stabilisation it is necessary and sufficient that the region $\Sigma \times]0,T[$ be large enough in the following sense: every bicharacteristic ray has to hit $\Sigma \times]0,T[$ at least once. The problem comes from space station technology.

M. BERCOVIER
(joint work with M. Durand, E. Jankovich)

The Development of a Mechanical Model for a Tire: A 15 Year Story to Replace Test Machines

Tires are very complex structures and their development necessitates extensive testing before production. A tire model must provide the engineer with a decision tool at the design stage. A complete 3 D nonlinear continuum mechanic's model has been built; based on this model, numerical simulations using the Finite Element Method are used as "test machines". The development of this model was done in stages: Cylindrical problems, large displacement, nonlinear (rubber type) materials, composite materials, 3D problems, contact on the road, rolling tire. This implied the parallel development of numerical procedures (special elements related to toroidal geometry, penalty method for incompressible materials, contact algorithms, effective solution of large stiff nonlinear problems). Today it is used by each development team of the world No. 2 tire manufacturer. But many questions are yet to be answered such as: rheological models, dynamic of obstacles, better solutions... As a conclusion we show how such a complex problem can be a rich source of challenges in mathematics, numerical analysis, mechanical engineering and other fields.

J. ALBRECHT

Eigenwertaufgaben im Ingenieurwesen - Einschließung von Eigenwerten

Es wurde über einige in den letzten Jahren in Clausthal entwickelte Methoden zur Einschließung von Eigenwerten allgemeiner Eigenwertaufgaben

$$M\phi=\lambda N\phi, \quad \phi\in D(M)$$

mit symmetrischen Operatoren M, N (entweder M oder N außerdem positiv definit), insbesondere über die Verallgemeinerung des Verfahrens von Lehmann durch Goerisch, berichtet; ihre Leistungsfähigkeit wurde durch numerische Resultate für verschiedene Eigenwertaufgaben mit partiellen Differentialgleichungen oder mit Systemen partieller Differentialgleichungen aus dem Ingenieurwesen (Schwingungen von Platten und Membranen, Schwingungen von Kreisbögen, Schlingern von Flüssigkeiten in Behältern, Wellen in Verbundwerkstoffen, Beulen von Platten unter Druck und Schub, hydrodynamische Stabilität) belegt.

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E.CUMBERBATCH

Mosfet Modelling

The stationary VAN ROOSBROECK equations for current flow in a MOSFET are reviewed, and the approximations used by physicists to get explicit formulae are described. Parameter identification techniques used at Claremont are described. Flow in the source/drain regions may be reduced to a linear B.V.P. which we have solved by a variational technique and also by singular perturbation analysis. Extensions to three-dimensional geometry are reviewed. The statistics of using 10^3 measurements of contact resistances for the yield of an integrated circuit (10^6 contacts) is introduced.

Berichterstatter: H.-G. Stark

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