MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

T a g u n g s b e r i c h t 26/1986

Optimalsteuerung und Variationsrechnung - Optimal Control

15.6. bis 21.6.1986

Die Tagung wurde geleitet von R. Bulirsch (TU München), A. Miele (Houston), J. Stoer (Würzburg), K. Well (Oberpfaffenhofen).

50 Wissenschaftler aus dem In- und Ausland haben an der Tagung teilgenommen, 10 Teilnehmer kamen aus den USA, des weiteren konnten Gäste aus der DDR, Österreich, Frankreich und Polen begrüßt werden.

Die Tagungsbeiträge spannten den Bogen von den Grundlagen bis zu praktischen Anwendungen. In grundlegenden Vorträgen wurden Verallgemeinerungen von Optimierungsaufgaben auf nichtkonvexe Probleme (Elster) behandelt, ferner wurde über neuere Arbeiten Dualitätstheorie (Klötzler), Optimalitätsbedingungen bei Problemen mit Hysterese (Brokate, Hoffmann) und über Optimierungsaufgaben mit Totzeit (Kowalewski) berichtet. Sehr interessant waren auch Beiträge über neuere Ansätze zur deterministischen Steuerung unsicherer Systeme (Leitman), Ansätze zur zyklischen Steuerung von ökonomischen Systemen (Feichtinger) sowie Beiträge über die zahlreichen Beziehungen zwischen klassischer Variationsrechnung und der Theorie der Differentialspiele (Marchal).

Neue numerische Verfahren wurden vorgestellt, z.B. Quasi-Newton-Algorithmen in Räumen unendlicher Dimension für sogenannte "unbeschränkte Probleme" (Sachs), und es wurde auch über Erfahrungen mit numerischen Methoden berichtet (Bock, Kraft).

Zahlreiche Beiträge waren den Anwendungen gewidmet: Im einzelnen wurde berichtet über Steuerungsprobleme mit verteilten Parametern, insbesondere über die Steuerung elastischer Strukturen (Cliff, Meirovitch), Untersuchungen optimaler Steuerungen von Robotern (Oberle, Leiner), optimales Reservoir-

Management von Wasserkraftwerken (Christensen) und optimalen Reglerentwurf (Longman) und effiziente Approximation mit Hilfe von Exponentialsplines (Rentrop).

In der Mehrzahl der Beiträge wurden Bahnoptimierungsprobleme bei Luft- und Raumfahrzeugen angesprochen. Zunächst wurde in einem Übersichtsvortrag über die Anwendung der Theorie der singulären Störungen auf derartige Probleme (Ardema) berichtet. Neben Problemen der Berechnung optimaler Steuerungen für spezielle Aufgaben (Pierson, Calise, Schnepper) wurde auch über neuere Ergebnisse und Vorschläge zur Berechnung periodischer Lösungen (Breakwell, Kelley) sowie über eine Reihe von Ansätzen zur Konstruktion geeigneter numerischer Verfahren, die so effizient und schnell sind, daß sie zur Echtzeitberechnung optimaler Steuerungen herangezogen werden können (Pesch, Bock, Grimm/Hiltmann, Bourdache-Siguerdidjane, Walden) berichtet.

Den Abschluß der Tagung bildete eine Panel-Diskussion über den Stand und Erwartungen bei der Anwendung der Theorie der Differentialspiele auf praktisch interessante Problemstellungen (Ardema, Breakwell, Kelley, Leitman, Marchal).

Vortragsauszüge

ARDEMA M.D.

Singular Perturbations in Nonlinear Optimal Control

Over the past 15 years, singular perturbation theory and asymptotic methods have been applied to problems of nonlinear optimal control with good success. In this paper we first briefly review both singular perturbation theory for nonlinear ordinary differential equations and the development of asymptotic methods in fluid mechanics and other branches of applied mathematics. These approaches are then applied to the nonlinear optimal control problem. The key requirement is found to be the stability properties of the singular points of the so-called boundary layer equations. These singular points are saddle-points of type n_f, where n_f is the number of fast, or boundary-layer, state variables. The special case of complete time-scale decoupling is considered; for autonomous systems, this leads directly to algebraic feedback control laws. Also briefly considered are linear-quadratic regulators. Finally, the use of singular perturbation methods in nonlinear optimal control is illustrated by representative applications to aircraft flight path optimization problems.

BOCK H.G.

BVP methods for direct and indirect solution of constrained optimal control problems

Boundary value problem methods and theory are a very helpful tool for the construction of effective numerical solution procedures for constrained optimal control problems. Two approaches are presented: the direct BVP approach parameterizes the control function by finite dimensional function spaces. Discretization of the ODE-system by multiple shooting collocation or finite differences yields large but sparse constrained nonlinear optimization problems. A seperation property is introduced which leads to block diagonalization of the Lagrange-Hessian and allows high rank update formulas which speed up the asymptotic convergence rate. The direct multiple shooting approach is completely dervative free, generates gradient information by (adjoint) internal numerical differentiation techniques. The indirect BVP

approach first transformes optimal control problem into a multipoint BVP which is solved by an adequate BVP solver. New developments in multiple shooting and collocation are described. The indirect approach is more complicated and requires substantial information about the rough structure, but it is very general and includes state-constraints, Chebyshev-problems and disconnected control regions. In addition, it can be extended to yield a neighbouring feedback control valid for the constrained case as well. All BVP approaches are numerically stable. Several application to demonstrate their performance are given.

BOURDACHE-SIGUERDIDJANE H.

On the synthesis of optimal nonlinear feedback laws

The paper is concerned with the automatic computation of the optimal nonlinear feedback control law, starting with a short review of the theory. The synthesis of a control system constitutes the main part of an optimization problem. We have shown, in previous papers, that the optimal nonlinear feedback control law satisfies a set of partial differential equations. The knowledge of the feedback law can therefore be considered of the hypersurface corresponding to the solution of these equations.
This hypersurface is computed off-line. Attractive features for real time implementation are discussed.

BREAKWELL J.V.

Oscillatory Cruise - A Short History

An expression is obtained for the second variation in the case of periodic variations about minimum-fuel cruise, the minimum being assured to occur at less than maximum thrust.
Sinusoidal variations in speed and altitude will generally produce some cost reduction for wave-lengths within a certain range, the reduction being due to two cause: i) δV in phase with $\delta\gamma$, implying a negative time-average for

the flight-path-angle γ, and hence assistance from gravity; ii) an increase of induced drag with altitude, so that $\partial^2 D/(\partial h \partial L) \times \delta h \delta L$ (δh being 180 deg out of phase with δL) rectifies to a negative value. Improvements indicated by reduced-order analyses, "energy-state" and "intermediate order", are related to cause (i).

Extrapolation of the second variation approximation to cost increase up to thrust variations δT of ± 60%, in the case of an aircraft studied by Grimm/Well/Oberle, gives close agreement with their optimal wave-length and δh, δV histories are fairly comparable with theirs. Best agreement is obtained by allowing a square-wave pattern for δT and solving for the optimal δL, assuming linearized dynamics and quadratic cost increase.

BROKATE M.

Systems with hysteresis

We consider time optimal control of a system whose dynamics consist of a system of ordinary differential equations and a nonlinearity of hysteresis type in the sense of Krasnolselski. We discuss existence and necessary optimality conditions and present numerical results, which are obtained by the multiple shooting algorithm.

CALISE A.J.

Necessary Condition for Optimal Pulse Control

Necessary conditions are presented for constrained variations that arise in the case of optimal pulse control. It is assumed that the pulse magnitudes and pulse durations are fixed, and that the only variables subject to variation are the pulse initiation times. These conditions replace two standard necessary conditions for optimality. Several missile control applications will be described.

CLIFF E.M. J.D.BURNS, F.H.LUTZE

Control of a Slewing Beam

A control problem is studied for a system consisting of rigid-masses connected by a flexible beam. A semi group formulation is employed to show that the resulting system of ordinary and partial differential equations is well-posed on a certain space. The control problem involves regulations over an infinte horizon of a finite number of outputs, using a single control torque. The Trotter-Theorem is used to motivate an approximation procedure and it is shown that the sequence of feedback operators for the approximating problems converges to that for the original problem. Numerical results are presented.

CHRISTENSEN G.S.

A New Approach for Optimizing Hydropower System Operation With a Quadratic Model

This paper is devoted to the development and application of a reservoir optimization model that yields monthly release policies. The generalization consists of the capability to handle nonlinear energy generation rates in the objective function (maximization of system annual energy generation). A quadratic model for the elevation-storage (average storage) is used.

The optimization problem is described and formulated as the opitmal control of a multivariable state-space model in which the state and control vectors are constrained by sets of equality and inequality relations. Lagrange and Kuhn-Tucker multipliers are used to adjoin these constraints to the objective function. The resulting cost functional is maximized by using the minimum norm formulation of the functional analysis. Numerical results are reported for a real system in operation consisting of three rivers; each river has two series reservoirs.

ELSTER K.H.

Generalized Conjugate Functions and Nonconvex Optimization

Since more than three decades, duality theorems formulated by FENCHEL-conjugate functions are considered as an essential and today as a classical part of the theory of convex optimization. Forthcoming numerous papers are devoted to extend the concept of conjugate mappings for treating nonconvex problems. In the paper the concept of ϕ-conjugations (DEUMLICH/ELSTER) will be handled and compared with several other new corresponding concepts. Moreover, applications to nonconvex optimization problems will be discussed.

FEICHTINGER G.

Endogeneous Optimal Oscillations

It is known that for one-state autonomous optimal control models the state variable is monotonic. Endogeneous cyclical solutions in continuous-time control models only occur if there are at least two states.
Two methods to prove the existence of periodic solutions in optimal control models are discussed. The first approach provides sufficient conditions for the existence of a cycle which is reached in finite time. Chattering is prevended by fixed transitional cost. The second method is based on Hopf's bifurcation theorem and deals with limit cycles. In both methods the oscillations are due to non-concavities in the Hamiltonian.
Both procedures are illustrated by economic examples. More specifically, applications in marketing (advertising pulsation), manpower planning (cyclical hiring and firing), inventory theory (oscillatory production rate) and other fields are sketched.
The purpose of the contribution is to demonstrate how optimal cycles can be established in economic control models.

GRIMM W., HILTMANN P.

Direct and Indirect Approach for Real-Time Optimization of Aircraft

Two methods for real-time optimization of aircraft are presented which attempt to satisfy time- and reliability requirements for on-line algorithms.
One method is based on the direct approach, i.e. it starts with a parametrization of the control functions. The computational work load is reduced by use of an effective integration scheme particularly designed for the underlying ODE-system. The robustness is enhanced by an active set strategy based on the elimination of parameters by active (nonlinear) constraints.
The second method is based on the indirect approach, i.e. it solves the BVP derived from variational calculus. The state and adjoint equations are solved by a collocation method. Extensions to constrained problems are also possible.
Both methods are taken as part of a feedback algorithm. Simulations are performed to test the accuracy of the feedback-guidance. The test problem is to maximize range in fixed time. The results are compared to the optimal solutions for the respective boundary conditions. Generally, a close agreement of opitmal and suboptimal control is observed.

HOFFMANN K.H.

Control of a free Boundary Problem with Hysteresis

We consider the problem of controlling the free boundary of the 2-phase Stefan problem by means of boundary hysteresis control based on the Preisach model. It is proved that for each control μ there is a corresponding solution of the Stefan problem and that there exists an optimal control. The asymptotic behaviour of the free boundary is investigated as well. Numerical work complements the theoretical results and gives some hints for further research.

KELLEY H.J., U. SHANKAR, E.M. CLIFF

Averaging Asymptotics for Optimal Powered Atmospheric Flight

An approximation scheme is proposed for dealing with the nonconvexity that generates "chattering" behavior in the energy-modelled version of the optimal-powered-atmospheric-flight problem. The "fast" motions are modelled in terms of optimal periodic control of a boundary-layer-like oscillation which does not die out but moves along with the progression of "slow" motion. The procedure represents a contrast to the usual singular-perturbation procedure for optimal-control problems in that the "fast" motions are calculated first over a range of values of the "slow" variables: The "slow" motions are then calculated using averaged rates.

KOWALEWSKI A.

Optimal Control of Distributed - Parameter System With Boundary Condition Involving a Time Delay and Initial State not a priori Given

The purpose of this paper is to show the use of Milutin-Dubovicki's method in solving some non-typical control problems for distributed-parameter systems. As an example, an optimal control problem for the system described by a linear partial differential equation of parabolic type with time delay in the boundary condition is considered. Also the initial condition is not given by a known function, but it belongs to a certain set / the initial state is not apriori given /. This equation makes in a linear approximation a universal mathematical model for the control of diffusion processes / e.g. plasma control / in which time delayed feedback signals are introduced at the boundary of a system's spatial domain and also exists some freedom in choosing the initial state of the controlled object. For the processes mentioned above the signal at the boundary of a system's spatial domain at any time depends on the signal which escaped earlier. This leads to boundary conditions involving time delays. In our problem the time delay in the boundary condition is constant. The performance functional has the integral form. The control time is fixed. Finally, we impose some constraints on the control. Making use of the Milutin-Dubovicki's theorem necessary and suffi-

cient conditions of optimality with the convex performance functional and constrained control are derived for the Neumann problem. The problem considered here is a generalization / the initial state not a priori given, more general performance index / of similar type as it was presented by P.K.C.Wang.

We also present a particular example in which the set of admissible controls and the one of initial conditions are given by means of the norm constraints. The application of the well-known projective gradient method in the Hilbert space allows to obtain the numerical solution of our optimization problem.

KLÖTZLER R.

Analytische und rechentechnische Aspekte zur Dualität bei Steuerungsproblemen

Es werden Grundlagen einer durch W.F.Krotow und dem Autor entwickelten allgemeinen Dualitätstherorie bei Steuerungsproblemen vorgestellt. Daran schließen sich einige Übersichten über alte und neuere Optimierungsprobleme an, die über diesen Zugang gelöst werden konnten. Abschließend wird ein Ausblick auf rechentechnische Nutzungsmöglichkeiten dieser Theorie gegeben.

KRAFT D.

Nonlinear System Analysis by Direct Collocation

A heuristic analysis approach of Nonlinear Systems is proposed which is based on solving a sequence of optimal control problems with varied problem parameters. Thus an engineering compromise as trade-off between constraint satisfaction and cost efficiency is possible. Processes are considered which are controlled by a two-degree-of-freedom controller. Various aspects of design efficiency lead to multicriteria problems for which Pareto-optimal solutions are sought.

The core of the algorithm deals with the solution of constrained optimal control problems by discretization and direct collocation. This leads to a nonlinear programming formulation with structured Jacobian and Hessian matrices. This is treated by sequential quadratic programming.

The procedure is examplified by the controller design for a cryogenic wind tunnel with three state variables and four control variables, three of which exhibit state dependent transportation time lags. Considerable performance increase is gained compared to heuristic engineering design approaches based on non-optimal design procedures.

LEINER U.

Steuerung eines Roboterarms auf einer vorgegebenen Bahn unter verschiedenen Optimialitätsbedingungen

Für ein drei-dimensionales Robotermodell werden Steuerungen gesucht, die bestimmte Optimalitätsbedingungen erfüllen. Dabei soll eine vorher bekannte Bahn von der Roboterhand nachgefahren werden. Als Optimalitätskriterium werden Minimierung der Fahrzeit und des Energieverbrauchs betrachtet. Die Vorgabe der Bahn wird zur Reduzierung der Anzahl der Differentialgleichungen verwendet. Lösungen wurden mit Hilfe der Mehrzielmethode gefunden. Für zeitoptimale Bahnen ergibt sich eine "bang-bang"-ähnliche Steuerstruktur mit unter Umständen mehreren Schaltpunkten. Bei energieoptimalen Bahnen ergeben sich - bei Hinzunahme von Steuerbeschränkungen - sowohl unbeschränkte wie auch beschränkte Teilstücke der Steuerung.

LEITMANN G.

Deterministic Control of Uncertain Systems

Many systems in the "real" world are subject to human intervention and control. The first step in devising a control policy or strategy for the accomplishment of a desired end is the abstraction of the perceived salient

features of the actual (physical, chemical, engineering, bilogical, economic, etc.) system. Such an abstraction is usually embodied in a mathematical model, e.g., ordinary differential equations, finite difference equations, partial differential equations, and so on. Mathematical models are always uncertain, partly because they are approximations involving unknown or partially known elements, and partly because they include elements which model uncertain effects in the real world. The equations describing the motion of an aircraft are the mathematical model of the aircraft; the aerodynamic coefficients are uncertain (perhaps known only to lie within certain ranges) and the aircraft resides in an uncertain environment (wind gusts, temperature variations, etc.).

Two avenues are open to the systems analyst dealing with such uncertain mathematical models, a statistical approach and a deterministic one. Our research effort has been devoted to the latter approach and, for the past dozen years, has dealt with systems modelled by ordinary differential equations. More recently, we have also considered and obtained some results for discrete models embodied in finite difference equations.

LONGMAN R.W.

Topics in Fixed Order Controller Design

The implementation of the linear quadratic results and of the pole placement results of modern control theory normally require on-line reconstruction of the state using, for example, a Kalman filter, and this produces a controller whose dimension is equal to that of the system. Such a high order controller is often unnecessary, with essentially equivalent performance being obtainable from lower order controllers. This paper addresses the question of how one can design optimal controllers of any prescribed dimension. First, a theorem on stability of a system by a controller of a chosen dimension is presented. Then algorithms to obtain fixed order controllers that are optimal with respect to a quadratic cost are discussed, and pole placement methods are presented where the remaining freedom after placement is used for optimization with respect to a quadratic cost. The issue of robustness with respect to system uncertainly is also considered for both approaches in terms of penalization of cost functional or eigenvalue sensitivity.

MARCHAL C.

Reduction of Deterministic Differential Games to Problems of Optimization - The Approximate Strategy Method

Deterministic differential games are necessarily competitive two-players zero-sum games and they require many cautions in order to avoid all hidden sources of undeterminism.
These games have been studied by many people since the early studies of R.Isaacs and they are characterized by a very large variety of singularities such as universal surfaces, dispersion surfaces, vocal lines, barriers, equivocal lines, etc.and it is generally extremly difficult to obtain the full solution of a game with many parameters.
A strategy, also called closed-loop strategy, is a choice of the control of one player in terms of the state of the game, the time and if possible the control of the other player. For a given strategy of one player the opponent faces an ordinary problem of optimization with one or several optimal solutions and thus a given value of the performance index.
It is almost hopeless to find directly the best strategies of both players but approximate strategies can be found easily and can be improved step by step systematically.
The strategies of the minimizer give upper bounds of the value of the game and those of the maximizer give lower bounds. These bounds may converge to the same value, the value of game; however, most game studies are terminated before this convergence takes place.

MEIROVITCH L.

Some Problems Associated With the Control of Distibuted Structures

Control of structures can be carried out conveniently by modal control whereby the structure is controlled by controlling its modes. Modal control requires estimation of the modal states for feedback which can present a problem for two- and three-dimensional structures. One approach that does not require modal state estemation is direct feedback control which implies collocated sensors and actuators. This paper examines some problems

encountered in direct feedback control of distributed structures in conjunction with pole placement. A perturbation technique permits the computation of control gains for multiinput systems. The paper demonstrates that the difficulties experienced in using direct feedback in conjunction with pole placement are endemic to the approach.

MIKULSKI L.

Optimal Design of Thin-walled Bars

The paper concerns determining of an optimal design of thin-walled bars with a bisymmetrical I cross-section. A deflection at a definite point or a bar weight have been accepted as a criterion of optimization. Constraints are imposed on overall dimensions and stresses. The height of a web or the width of shelves are taken as control variables. The classical assumption of a technical theory for thin-walled bars hold during derivation of state equations. The effective Pontryagin method is used for solving the formulated problems. The routine BNDSCO is used for the numerical solution of boundary value problems with switching conditions.

OBERLE H.J.

Numerische Berechnung singulärer Steuerungen für die Bewegung eines Roboterarms

Es wird das Modell eines reibungsfrei gelagerten zweigliedrigen Roboterarms betrachtet. Die Zustandsgrößen sind: Ellbogenwinkel α, Winkel θ des Oberarms bezogen auf seine Ausgangslage sowie die beiden Winkelgeschwindigkeiten $\omega_{1,2}$ von Ober- und Unterarm. Die Bewegung wird gesteuert mittels der an Ober- und Unterarm angreifenden Drehmomente $Q_{1,2}$. Aufgabe ist es, die Steuerung so vorzunehmen, daß die Spitze des Roboterarms eine vorgegebene Entfernung X_L in kürzester Zeit zurücklegt. Dabei soll der Arm zu Beginn und zum Ende der Bewegung in Ruhe sein.

Für dieses Problem haben Bryson, Weinreb (1985) Lösungen vom bang-bang Typ angegeben. Ziel dieser Arbeit ist es nun zu zeigen, daß für gewisse Entfernungsvorgaben X_L singuläre Steuerungen für das Oberarm-Drehmoment auftreten können. Hierzu werden die notwendigen Bedingungen der Variationsrechnung aufgestellt. Durch zweimalige Differentiation der Schaltfunktion gelingt es, einen expliziten Ausdruck für eine singuläre Steuerung Q_1 zu erhalten. Somit läßt sich - in Abhängigkeit der Schaltfunktion - ein Randwertproblem mit Schaltbedingungen aufstellen, welches mit der Mehrzielmethode numerisch gelöst wird. In Abhängigkeit von der Reichweite X_L erhält man so zwei Lösungszweige, wobei der Lösungszweig mit asymmetrischen Steuerungen für mittlere Reichweite singulär Teilstücke aufweist.

PESCH H.J.

Echtzeitberechnung fastoptimaler Rückkopplungssteuerungen bei Steuerungsproblemen mit Beschränkungen

Viele Optimierungsprobleme in Naturwissenschaft und Technik können mathematisch durch optimale Steuerungsprobleme beschrieben werden, wie z.B. die Steuerung eines Raumfahrzeuges oder eines Flugzeuges, einer chemischen Reaktion oder eines Industrieroboters. Sollen diese optimalen Lösungen praktisch realisiert werden, genügt es nicht, Anfangsdaten vorzugeben und den Prozeß sich selbst zu überlassen. Vielmehr benötigt man schnellste Rechenverfahren, die den zukünftigen Verlauf der optimalen Steuerungen eines gestörten Prozesses noch während seines zeitlichen Ablaufs berechnen und einstellen, damit Optimalitätsbedingungen und vorgeschriebene Beschränkungen trotz auftretender Störungen erfüllt bleiben.
Das in dieser Arbeit entwickelte Rechenverfahren zur schnellen numerischen Berechnung fastoptimaler Rückkopplungssteuerungen ist sehr allgemein auf beschränkte Optimal-Steuerungsprobleme anwendbar. Alle Beschränkungen können vor der Rückführung überprüft werden. Bezüglich Rechenzeit und Speicherplatzbedarf ist das Verfahren für den Einsatz in Bordrechnern geeignet. Die erfolgreich korrigierbaren Abweichungen liegen weit über den bei Raumfahrtunternehmungen auftretenden Störungen.

Wer fliegt mit?

PIERSON B.L.

A Model Comparison of a Supersonic Aircraft Minimum Time-to-Climb Problem

A minimum time-to-climb problem is formulated as a parameterized optimal control problem and is solved using sequential quadratic programming. Five dynamic models are treated. The five-state model features the usual point-mass equations of motion for flight in a vertical plane. Time is the independent variable, and speed, altitude, flight path angle, range, and mass are the dependent variables. Range is used to replace time as the independent variable for the remaining four models. The last of these is the well-known energy-state approximation with specific energy as the only state variable and speed as the control variable. The primary objective is to compare the solutions for each of the five models with regard to accuracy and computational effort. Numerical results are presented for an early representation of the F-4 fighter aircraft.

RENTROP P.(COLLOBORATION WITH U.WEVER)

Computational Strategies for the Tension Parameters of the Exponential Spline

Three different strategies to determine the tension parameters p_i of the exponential spline (or spline under tension) are discussed. A first heuristic strategy is based on the knowledge of the interpolating cubic spline and p_i-values are proposed in order to eliminate undesired inflection points. Convexity or monotonicity of the interpolant cannot be guaranteed. A convexity preserving C^2 - interpolant (if possible) is constructed by solving a constrained nonlinear optimization problem for the tension parameters p_i. Ths second strategy characterizes an "optimal" set of p_i - values. The optimization problem is the base to derive "a priori" estimates for the p_i in a third strategy. The convexity arguments are supplemented by monotonicity constraints. The performance of all strategies is demonstrated in several examples.

SACHS E.

A Pointwise Quasi-Newton-Method for Unconstrained Optimal Control Problems

For a class of unconstrained optimal control problems we propose a quasi-Newton method that exploits the structure of the problem. We define a new type of superlinear convergence for sequences in function spaces and prove superlinear convergence of the iterates generated by the quasi-Newton method in this sense. The method is applied to a simple unconstrained optimal control problem and numerical results are presented.

SCHILLING K.

Boundary Value Problems for Differential Inclusions and the Computation of Optimal Trajectories

Simplicial algorithms allow the computation of fixed points -even for set valued real mappings. The extension of known convergence theorems to Banach spaces enable constructive fixed point results based only on compactness and continuity principles.
The application to boundary value problems for differential inclusions will be presented deriving thus an extension of numerically treatable problems to Peano-type dynamics.
This result is of particular interest for optimal control theory, as the necessary conditions of the Pontryagin Maximum Principle can be interpreted in this context. There results a new indirect method for the computation of optimal trajectories with advantages for bounded control domains, for problems with singular control arcs or without differentiability properties.
A numerical example about optimal harvesting of fish populations will be given as illustration.

SCHNEPPER K.

Pursuit-Evasion With a Chattering Junction of Non-Singular and Singular Subarcs

A simple two dimensional constant velocity pursuit-evasion scenario is considered. From that scenario a time optimal control problem is posed which is linear in the control. The solution consists of a bang-bang control with possible singular arcs. It is shown that a junction between non-singular and singular arcs must be of a chattering type.

SZEFER G.

Sensibilität und optimale Steuerung elastischer Strukturen mit verteilten Parametern

Die Entwicklungstendenzen der modernen Optimierungstheorie in der Mechanik führen zur Kopplung von drei Formalismen: Der Variationsrechnung, der Steuerungstheorie und der mechanischen Theorie der Energieprinzipien. In der Arbeit wird ein Verfahren der Optimierung elastischer Systeme mit verteilten Parametern präsentiert. Es werden sowohl lineare als auch nichlineare Operatoren des Zustands betrachtet. Die Zustandsgleichung des Systems wird in variationeller Form dargestellt. Unter der Voraussetzung, daß alle in dem Problem auftretenden Funktionale Gateuax-differenzierbar sind, werden die Sensibilitätsoperatoren effektiv konstruiert. Dabei spielt das Konzept der adjungierten Gleichung die entscheidende Rolle. Beispiele aus der nichtlinearen Plattentheorie illustrieren die Effektivität der Methode.

WALDEN R.

Aircraft Trajectory Optimization by Curvature Control

A new mathematical model for operational aircraft trajectory optimization is introduced. Control functions are curvature and torsion of the trajectory. Examples of the usefulness of this model are given.

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