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WARSZAWA 16 – 21 JUNI 1969

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Naczelna Organizacja Techniczna w Polsce

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C o n t e n t s

A Predictive Control Scheme for Dead-Time Process Using a Learning Method of Process Identification

M.S.Beck, P.R. Birch, N.E.Cough, A. Plaskowski

This paper describes the implementation of a feedback/predictive control scheme on a pilot scale process with dead-time, using a process control computer. This process is a representative of a broad class of processes where dead-time makes accurate control difficult when conventional feedback control is used. A performance criterion which takes into account the econmic and safety requirements of the process is used. A hill-climbing procedure optimises the performance of a model representing the part of the process without the time delay, the optimum control signal is then stored for the duration of the time delay before applying it to the process.. Various optimising procedures have been tried and it is shown that a particular iterative procedure gives assured convergence with a short computing time, which is substantially independent of the order of the system.

The predictive control scheme overcomes the problems of stability in using feedback control, leaving a feedback loop to only correct for process drift. Acceptable feedback control settings determined by a computer program which periodically calculates the process controllability.

A particular feature is that the model can be completely specified by the impulse response of the process. Discreet points on the impulse response curve are stored by the computer and up-dated from time to time. A pseudo-random binary sequence test signal is used to determine the impulse response model, which can be computed by direct cross-correlation, or by a new learning method. In the learning method any "a "priori" information about the process dynamic behaviour is used as an initial process model. This initial process model is up-dated by a learning procedure to give an up-dated process model which accurately matches the process.

Computer requirements for the basic feedback/predictive control scheme with correlation identification are, approximately, 3,700 words of core store, between 12 and 25 m s. calculation time per sampling instant, plus 2 seconds calculation when an identification is required.

CONTROL OF SYSTEMS WITH TIME DELAY

by Gunnar Nielsen lic. techn.
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The control of systems with time delay is of considerable importance. Several methods to perform this control have been published, but only very little concerning practical experience with the methods.

This paper reports the results of a study where these methods are compared. The comparison is done quantitatively using the IAE performance index. The control obtained is discussed for both setpoint and load step changes. Results are given as functions of the relative delay i.e. the ratio of the delay to the sum of the delay and the time constants. Among the methods tested are ordinary I, PI and PID-control, sampled data control, the Smith linear predictor and some feedforward schemes.

SINTHESIS OF QUASI-OPTIMAL MINIMUM TIME CONTROL BY WAY OF APPROXIMATING SIGNUM-FUNCTIONS

L.At.Gunchev

The problem of approximating of the optimal minimum control function is considered. The possibility to realize quasi-optimal control input for linear plants by means of equivalent approximating functions is shown. Equivalent building functions are suggested in the class of practically applicable functions.

The possibility to design quasi-optimal control device using linear and realy components only is demonstrated. The method suggested determines the structure and parameters of the quasi-optimal controller. The experimental data obtained confirm the effectiveness of the method of equivalent signum-functions.

RELAY CONTROL OF SYSTEMS WITH
PARAMETER UNCERTAINTIES

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The design of a relay controller for model-tracking systems is developed, taking into account the effect of parameter uncertainties. By employing a semi-definite Liapunov function, it is possible to treat multi-output systems, or more generally, systems whose state variables are not necessarily in phase-variable form. It is shown that the plant can be forced to track a model with bounded error if bounds on the parameter deviations are known. The method is applied to a specific design problem involving an unstable plant.

DESIGN OF LIMITED-INSTRUMENTATION CONTROL

SYSTEMS FOR DISTRIBUTED PROCESSES.

by M.J. McCann,
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Because the theory of optimal control of distributed processes leads to extremely difficult computational problems an alternative approach is required. This paper describes a method which can give designs for both linear and relay (bang-bang) control of linear distributed processes which are subject to distributed disturbances. The designs are intended to yield control systems in which instrumentation (measurement) in the process is extremely limited. The method requires, in any application, that a simulation of the distributed process be available which shows internal behaviour and not just an overall (input-output) representation. The method is a search and adjustment procedure which can be programmed but is simple enough to be done more easily by the user.

SOME PROBLEMS OF CONTROL PLANTS IDENTIFICATION

S.A. Anisimov, N.S. Rajbman
F.A. Hofsepian, O.F. Hans

For complex equipment the type of equation for the equipment is not known a priori, and in this connection a number of complementary problems of identification emerge. These problems include the determination of the characteristics of the coupling between the input and output variables, a ... quantitative evaluation of the degree of homomorphousness of the original equipment and the degree of non-linearity, determination of the form of equation for the equipment, etc. The paper pays main attention to statistical methods of identification according to data on the normal function of the equipment. Four types of equipment are being considered, in accordance with the fact that the input as well as the operator may be random or determined. The link is established between the methods of investigation of all the types of equipment.

SENSITIVIZING INPUTS AND IDENTIFICATION

A. RAULT - R. POULIQUEN - J. RICHALET

The identification of systems by the model method leads to the minimization of a function of structural parameters representing the distance between the system to be identified and the investigated model. This distance can be a distance of structure or a distance of state. In the first case we shall show that the procedure of identification can boil down to the determination of the laws of variation in the parameter space. In the second case identification seems to boil down to a simple problem of parameter optimization. However, it is shown that the precision of an identification is connected with the form of iso-error locus, that is to the sensitivity of parameters.

So we introduce the relation existing between identification and sensitivity coefficients. Then we shall define a sensitivization index which gives a measure of the distribution of information and permits to define inputs called spherizing inputs which distribute it equally on all the parameters or sensitivizing inputs which concentrate it on a given parameter.

To consider identification under this angle constitutes progress in the sense that from now on it is possible to evaluate the quality of identification and to fix a test protocol.

PROCESS DYNAMICS IDENTIFICATION
BY THE MULTISTEP METHOD

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The step response test is a practical method widely used for process dynamics identification, because of its simplicity and the short time required to obtain a significant result. But in many cases external disturbances corrupt the observed signal, and it becomes necessary to repeat the test many times in order to obtain valuable estimates. This results in a longer testing period of time, and reduces by the same time the advantage of the method. In this paper, an extension of the step method, called the multistep method, is proposed. The identification signal is a sequence of steps applied to the input at a frequency higher than $1/T_o$ (where T_o represents the finite memory time of the system). The main advantage of the method is that for a fixed testing period of time, more information may be now extracted from the observed signal.

The author analyses the computation procedure (resulting in the step response which is presented in sampled data form) and shows how the choice of specific sequences simplifies the amount of computations. In fact, no inversion of matrices is required, and, by the same time, any portion of length T_o extracted from the observed signal will give a result (more or less corrupted by noise). These specific sequences are then extended to the case of a multiinput system. The best statistical estimation of the step response through the collected results is not discussed.

A THEORY OF PARAMETER TRACKING APPLIED TO SLOWLY VARYING NONLINEAR SYSTEMS

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A stochastic system is defined using a set of density functions. For this system a bayesian tracking problem is formulated and the solution is given as a recursive algorithm. In the general case the algorithm requires rather complicated computations.

As a special case an exactly observable linear Gauss-Markov system is investigated, and in this case the algorithm requires only matrix computations. It is essential for the solution that the system is exactly observable, because it is probably the only case where one can avoid products of random variables.

The method is applied to nonlinear systems where the variations in signal amplitude are slow enough to admit linearization over short time intervals, which makes it possible to look upon the effects of the nonlinearity as caused by variations in parameter values of the linearized system.

As an example the simulated tracking characteristics of a saturating system and a system with exponential nonlinearity are investigated. The results are satisfactory.

THE APPROXIMATION METHOD OF IDENTIFICATION

H. Górecki

A. Turowicz

Summary

The approximation method in the L-space for purposes of identification control processes is consideres. The method is based on theorems of Steinhaus, Markov and Sobolev.

In the case of a function one variable $f(x)$, if we suppose that in the class of polynoms whose degree does not exceed n, exists the polynom $P_n(x)$ such that 1° $\int_a^b |f(x) - P_n(x)| dx = \min$, and 2° The difference $f(x)-P_n(x)$ changes the sign in exactly $b+1$ points in $[a,b]$ then the abscissas x_k of these points are zeroes of the Tchebyshefs polynom $T_{n+1}(x) = \cos[(n+1) \arccos x]$. Hence one needs to measure the function $f(x)$ on by in these points.

In the case of a convex function of n-variables the conditions for the optimal linear approximation in L-space are given.

ON THE SELECTION OF SUBGOAL AND

THE USE OF APRIORI INFORMATION IN LEARNING CONTROL SYSTEMS*

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Numerous methods have been proposed for the design of control systems which learn to function in unknown or partially known environments. Most learning schemes are radical departures from the techniques using continuous adjustment of parameters which grew out of early developments in model reference systems. Principal contributions to the area have been controller models and algorithms. In studying these models, the system is abstracted to such an extent that there is quite often a loss of contact with practical considerations. The objective of this paper is to present some results in the theory of learning control, but also to look again at some of the practical problems encountered in applying a learning controller to a problem.

This paper defines the subgoal as a subordinate to the primary goal of minimizing the performance index. It must evaluate each decision one control interval after it is instituted. The subgoal problem is to choose a subgoal which will direct the learning process to the optimal as prescribed by the given performance index. An analytical solution is presented and extended heuristically for the general case. This extended method makes use of the apriori information about the plant.

Two other problems are also discussed. A fixed grid is used to partition the state space into control situations, and a method of extending the grid is proposed and evaluated. The controller is initialized using the apriori information, too. A full scale simulation confirms that the proposed methods of choosing the subgoal, extending the fixed grid and initializing the controller are improvements over previous methods.

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ON SOME CLASS OF ADAPTIVE (SELF-LEARNING) SYSTEMS

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The report deals with the theory of one special class of adaptive systems. The apparatus of finitely convergent algorythms for the solution of the infinite systems of inequalities is taken as the basis. The general outline of the problem is as follows. The system is said to be adaptive if its functioning law changes with the experience acquired. Some information is supplied to the system on 'success' or 'failure' of its conduct to some aim condition. It is essential, that some characteristics of the surroundings and the system as well as, probably, some parameters of the aim condition are assumed to be unknown to the designer. They may be any of a certain class M. The adaptive system (AS) is said to be reasonable in class M, if for any aim condition and any characteristics of this class there exists an instant after which the aim condition is fulfilled every time. The problem consists in construction of a system, reasonable in the given class M.

The report gives a formalized stating of the simplest variant of this problem, and, along with some additional suppositions, the solution of this strictly formulated problem. The results are given of simulation on the computer of the self-learning process of one simple mathematically styled system "reasonable" in the given rather conventional sense.

ON THE ALGORITHM OF LEARNING WITH THE ACCUMULATION OF EXPERIENCE

Štefan Petráš

Summary

In solving problems of optimum control with incomplete information on the controlled object there frequently arises the basic question of how to determine an appropriate algorithm of control, especially when the system is multidimensional and exposed to perturbations. Deterministic methods are no longer suitable for these purposes. Stochastic methods are used.

The paper introduces new algorithms of learning. These algorithms are discretely stochastic. They represent, as a matter of fact, a complicated Markhovian process of the k^{th} order. The realization of the random unity vector is determined by the conditioned probability of the storage parameter. The decision proper is done on the basis of the Bayesian decision or the maximal aposteriorial probability principle, respectively.

It is proved that under certain presumptions such process is a martingal or semimartingal process. The convergence of such processes is introduced.

On a concrete example the procedure of seeking the extremum of the function is shown that describes the controlled object. The described algorithms are suitable for controlling steady-state continuous production processes by means of automatic computers.

On the Ergodicity and Dynamic Behavior of Finite-State Markov Chains

H. H. Yeh J.T. Tou

Summary

Learning theory has made extensive use of Markov chains as mathematical models. It also has been established that the stochastic finite-state automaton which plays an important role in engineering systems involving artificial intelligence is representable by a finite-state homogeneous Markov chain.

This paper studies the ergodic properties of finite-state Markov chains via the notion of norms of vectors and matrices, the concept of induced operators and the principle of contraction mapping in the finite dimensional linear space.

It is found that if the smallest norm of the induced transition matrix on the invariant subspace S_o whose normal is (1, 1, ...) is less than one, the chain is ergodic and operates as a contraction mapping on subspace S_o. Conversely, if a finite-state homogeneous Markov chain is ergodic it is a contraction mapping on S_o. The norm of the induced transition probabily matrix serves as a pessimistic estimation of convergence rate.

A general test procedure is summarized for determining the ergodicity and convergence rate of a finite-state homogeneous Markov chain. A necessary and sufficient condition for ergodicity is derived from this procedure together with other ergodicity criteria for special cases. It is found that ergodicity is determined by the form of the transition matrix and has nothing to do with the numerical values of the elements of the matrix.

STATISTICAL MIN-MAX DECISION METHOD AND THEIR APPLICATION TO LEARNING CONTROL

Bunji KONDO and Shigeru EIHO

This paper deals with the statistical decision method used as a learning mechanism in the optimalizing control systems. The min-max decision function is treated where we have little knowledge about the system. The sub-optimal min-max decision function is generally given as a function of the data of past experiences with the help of the theory of games and the technique of linear programming. This strategy is available when the number of data is small.

Moreover, this paper deals with the learning mechanism which changes the decision strategy from the min-max solution to the Bayes solution as the number of data increases.

CONTROLLABILITY AND SYNTHESIS OF OPTIMAL, DYNAMICAL SYSTEMS

F.M. Kirillova, R. Gabasov, I.A. Poletajeva, S.V. Tzurakova

The paper examines two types of controllability of systems with complex sequence, dependent on time, the state of the installation, the control action applied.

Systems in which disturbance ends before a set moment of time, are called relatively controllable. If after the disturbance has ended the control switches off, then the system cannot follow the required duty because of sequence. For this reason the problem of the full controllability of the system arises.

The authors indicate the indispensable, sufficient conditions of controllability / relative, full/ for systems / linear, non-linear/ with sequence. These conditions are expressed through the coefficients of differential equations / transfer functions/ of the installations.

An investigation is made of critical cases of the controllability of non-linear systems, when equations of linear approximation do not allow to evaluate the controllability of the system.

A number of problems concerning the optimisation of systems with sequence are formulated in the paper. Conditions are found, which satisfy the optimum control / the best in the sense of the chosen criterion/. It is shown that in many cases these conditions are sufficient for the optimum. In the particular case of usual dynamic systems the conditions of the optimum obtained pass into L.S. Pontryagin's well-known maximum principle. A new form of recording the conditions of the optimum is proposed, one which, while maintaining the elegance of L.S.Pontryagin's formalism, distinguishes itself by greater universality. This form is maintained for systems which are described by diverse equations / integro-differential, integral equations, equations in particular derivatives/, and because of its simplicity it can be useful to engineers dealing with the optimisation of complex installations.

The necessary optimum conditions are derived in one problem of the minimization of the quality function.

A number of criteria are stated, with which the optimization problem has a solution, that is one may consciously find a control that is better than others in the set class. The procedure of investigating special optimum controls is worked out, its application to the theory of sliding duties is given. A number of control laws for the numerical solution of optimum control problems is proposed.

The paper gives a review of the contemporary state of the problem, of the existing methods of synthesis, the approach of the functional analysis to the problem of synthesis is described, new results achieved by the authors in this direction , are presented.

It is shown that the used diagram may be transferred on problems of the optimization of dynamic system in situations. The results are formulated regarding the existence of optimum control and the necessary optimum conditions in these problems.

In conclusion the question is considered of the theory of optimum processes in continuous systems being spread to the sampling systems. The specific particularities of the developed theory are noted. A number of results are presented regarding the necessary and sufficient optimum conditions of sampling systems.

INTEGRALS OF SET VALUED FUNCTIONS AND LINEAR OPTIMAL CONTROL PROBLEMS.

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Let $P(t)$ for $t \in [0,1] = J$ be a closed subset of finite dimensional linear space E. By $\int_0^1 P(t)dt$ we mean the set $\left\{\int_0^1 u(t)dt\right\}$, where u is integrable on J and $u(t) \in P(t)$ almost everywhere in J. So defined integral of set valued function has applications to some linear control problems.

Till now only the case $\int_0^1 P(t)dt$ is a bounded set has been studied. In the present paper we examine for the first time the case when the integral can be an unbounded set.

OPTIMAL CONTROL SYNTHESIS USING FUNCTION DECOMPOSITION TECHNIQUES

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Optimal control functions belonging to linear manifolds of the control space are synthesized from components of the basis-functions which span them. A lower bound for the minimal performance index is developed which can be calculated when only non-optimal controls are available. Using this, a simple condition is found for the optimal control belonging to a linear manifold to be an arbitrarily close approximation to the optimal control belonging to the control space - for any particular initial condition. A simple procedure is outlined for ensuring that the linear manifold considered is such that the control law determining the optimal control belonging to the linear manifold (as a function of the initial conditions) is an arbitrarily close approximation to the control law which determines the optimal control belonging to the control space.

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About the Determination of the zones of emission and optimal trajectories for the nonlinear control systems

Summary

In the paper the new method for the determination of the zones of emission for the nonlinear control systems is considered. This method is based on the theory of orientor fields. Using this method it is possible to calculate the 1-st order partial differential egation. This equation derscribes the surface which is boundary of the zone of emission. It is possible to calculate the optimal trajectory solving the above equation by the method of characteristic stripes of Cauchy. Following this way we can reduce this problem to the system of Hamilton type ordinary differential equations. These equations are analogous to the equations of Pontriagin, but the interpretation of them is quite different. The problem which is considered is closely related with the "bang-bang" type of control, and for that reason may have a great practical meaning.

OF MULTISTAGE GAMES

A.I. Propoy

The discrete games with fixed step number are described in this paper. Using similar games as an example, the different ways of putting the prblems are discussed. The problems may partain discrete and continuous /differential/ games as well.

Nesessary optimality conditions will be obtained when the game containes a saddle point.

Sufficient conditions are given to assure the saddle point in the game. Individual cases are also discussed.

Necessary optimality conditions are obtained which allow to discribe the lower and upper game estimator, that is to say, for minimax and maximin stratgies.

Numerical methods for multistep games are also considered. The possibility of extending the obtained results for differential games are discussed.

MAGNETIC ADAPTIVE COMPONENTS FOR AUTOMATIC CONTROL SYSTEMS

M.A. Rozenblat, M.A. Boyarchenko

(MOSCOW)

To construct an adaptive system of automatic control, often necessary elements, which fullfill following function are aplied:

$$\mathcal{Z} = x\,F(y,t) \quad (1)$$

where x - output uninterrupted varable,

y - actuating signal calling for change of element transfer coefficient according to adaptive function $F(y,t)$

Four typical adaptive functions can be extracted:

$$F(y,t)\; t > t_0 = F/y(t_0)/ = K \cdot y(t_0)\,; \quad (2)$$

$$F(y,t) = K \int_{0}^{t} y\,dt\,; \quad (3)$$

$$F(y,t)\; t > t_0 = F_1 / \sum_{j=1}^{n} \Delta y(t_0) /\,; \quad (4)$$

$$F(y,t)\; t > t_0 = K \operatorname{sign} y(t_0) \quad (5)$$

In the first event (2) adaptive function is reduced to rememberance of adaptive signal "y" in some time period "t_0". In the second event (3) adaptive function is equal to an integral of actuating signal "y", which often represents a differential of given and actual meaning of some of the controlled control parameter.

In the third event (4) adaptive function represents some sort of monotonuous /but not necessary uniform/ function of increment sum of control signals, which enter corresponding adaptive element at any moment t_1, t_2, t_3, ... Adaptive function (4) usually is used in systems, which are adapted by sequential search method or by study. Adaptive function (5) takes only three sampled meanings(-k , 0 , +k), from which very often only two are used, f.i. 0 and k , or -k and k. Common for all four adaptive functions is this, that they have memory. For this, for conveying of functions (2-4) necessary analogue memory elementsare necessary, for function (5) - sampled /double or treble/ are necessary. Therefore it is recommended to use features of ferromagnetics and pithes with square hysteresis hinge in construction of adaptive elements,

Any adaptive element can be constructed by corresponding insertion of memory element, which fulfils adaptive function F (y , t) and that of a standard analogue multiplyfying installation.

But the most interesting are elements where adaptive and multiplyfying functions are combined in one installation. In this paper discussed are main points of solution of a/m adaptive functions on magnetic pithes with squarw hysteresis hinge and of construction methods of magnetic adaptive elements with limited connection of adaptive an multiplyfying functions.

EXTERMAL STATISTIC AND DYNAMIC RESPONSE OF INPUT-OUTPUT SEQUENTIAL LOGICAL ELEMENTS

N.P. Vasileva

Derivative queueing schemes can be made in a form of a closed networks, consisting of other closed networks, specially of such as triggers, outside characteristics of which, define stability of work as outside closed networks as well as all queueing scheme as a whole.

Outside characteristic is understood as a characteristic of input - output closed elements circuit with reference to input and output outside signals in distinguishing of internal input - output characteristics of opened circuit of those elements.

Basing on analysis which was made on some trigger examples, typical for mostly used in logical element automatisation and on queueing schemes, was shown following:

1. Appearance of outside dynamical and statistical trigger characteristics and other queueing schemes depends on the means of signals summation in feedback networks.
2. At diode summation of input signals in triggers and other queueing schemes, feedback signals do not increase gain constant of internal characteristics of those schemes.

In outside statistical characteristics of triggers and other queueing schemes a relay jogging may occure.

Unstability of queueing schemes are defined by the worst of internal characteristics, i.e. separate queueing elements characteristics and of their cascade circuits which form scheme.

3. At arithmetic summation of input signals in triggers and other queueing schemes, feedback signals violently increase the gain constant of their outside dynamical characteristic, to the extend that it can go into negative field. At this scheme unstability at zero or one decreases.

Such triggers statistical characteristics, have relay jogging at abscisses of the unstable balance point of the outgoing internal trigger characteristics.
Therefore the worst triggers characteristics with arithmetic summation are their outside characteristics, critical points of which, must be used for triggers control.

4. Outside dynamical characteristics of synchro-dynamical triggers, specially of digital triggers, coincide with internal dynamical characteristics of those triggers, which are themselve functions of all trigger inputs including input of feedback.

PRIMARY DATA PROCESSING DEVICES OF CONTROL COMPUTERS ON QUANTUM MAGNETOMEASUREMENT PRINCIPLES

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Increasing requirements to the data quality about technological processes in the objects checked out and controlled by a central computer have demanded developments of new electrical value and angle - shift conversion fundamentals having accuracy, realization simplicity, good dynamic values and convenience of alignments with the central computer.

The report shows that the natural tendency towards the perfection of precision frequency converters both of the "analog--code" and "angle - code" types is the development, for the purpose, of nuclear spectroscopy frequency fundamentals widely-known and used in magneto-measurement practice. These fundamentals are the basis for the development of the first quantum type devices /for instance, radio range masers/.

The nuclear spectroscopy deals with atomic constants such as gyromagnetic nucleus or atom relationship. At present in investigating the Earth magnetic field, the magneto-measurement technique makes use of highly stable quantum magnetometers /magnetic masers/, their characteristic feature being the practical nondependence of their output frequency on the ambient medium parameters. Such sensors are practically of an ideal linearity and a high sensitivity. They may rather efficiently applied for the production of large - scale precision converting devices. The use of creogenic technique elements and nonstationary phenomena of a nuclear magnetic resonance in quantum converters opens up particular possibilities to control little changes in the magnetic field strength playing the role of an intermediate parameter of the conversion process.

THE MEASUREMENT OF SPECIFIC GRAVITY BY MAGNETIC REPULSION

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A float with a permanent magnet is put in the liquid and another magnet (permanent magnet or electro magnet) is placed outside the liquid to suspend the float by magnetic repulsion. Also this outside magnet is hanged on one arm of a balance. It is shown theoretically that the apparent increase of mass of the outside magnet is equal to the apparent mass of the float in the liquid. This is the measuring principle of this method and is proved through experiments. In this method, it is unnecessary to know the position of float in the liquid and the strength of the outside magnet, that is, the measurement is not affected by the change of the magnetic strength by some reasons, so long as the magnet has sufficient strength for suspending the float within the liquid.

This method is suitably applicable to measure the specific gravity of liquid in automatic control system.

A GENERAL METHOD FOR THE DESIGN OF LINEAR AND NONLINEAR CONTROL SYSTEMS

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A method for the practical design of feedback control systems for linear and nonlinear plants is described, which is based on the following principle:

1.) Parallel compensation of the plant by modelling the plant (for the purpose of stabilization of the control loop and selection of the disturbance response) and

2.) Cascade compensation of the plant (for the purpose of optimal manipulating).

Constructing the controller by this way, the design problem is reduced to a pure open-loop problem, which can be solved by optimal approximation of the inverse structure of the plant without considering the stability of the closed loop. It will be shown, that, even for complex plant, the method gives an assertion about the respective limits of a control and leads conclusively to the corresponding structure of the controller. The application of the method on linear plants with lumped or distributed parameters and on nonlinear plants is investigated. As an example, the design of a nearly time optimal continuous control system for a first order plant with saturation is demonstrated.

AN ALGEBRAIC METHOD FOR FOLLOW-UP SYSTEMS COMPENSATION

by

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Proceeding from the presentation of a sequential system as a norm polynomial form and a norm function form, a method is being derived, which transforms sequential systems into this form. The compensation elements necessary here result, with the conditions of realization being considered, directly from the system under consideration. It turns out that, for application, one may proceed from the locus of the system. The parameters of the compensation element can be obtained here by means of a graphic method. It results furthermore that the investigated element can be replaced by approximation which, being easily applicable, produces good results. The derived method is being presented by means of an example.

A SIMPLE PROCEDURE FOR THE SYNTHESIS OF SAMPLED-DATA-CONTROL-SYSTEMS BY MEANS OF THE BODE-DIAGRAM-TECHNIQUE

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A procedure is proposed by which the wellknown advantages of the Bode-Diagram-Technique for continuous control-systems can be transferred directly to the synthesis of sampled-data-control-systems. The considered sampled-data-systems consist of control systems governed by a differential equation, a zero order holding device and a controller described by a difference equation or a transfer function respectively

$$G(z) = \frac{d_o + d_1 . z^{-1} + \ldots + d_n . z^{-n}}{1 - c_1 . z^{-1} - \ldots - c_n . z^{-n}}$$

of classes $n = 1,2,3$.

For direct application of the Bode-Diagram-Technique a transfer-function $G(p) = G_1(p) \cdot G_2(p)$ describing zero order hold and controller in the space $\omega = 0 \ldots \Omega$ is given. $G_1(p)$ describes an ideal, continuous controller with PD-, PID-, PD_2- or PID_2-time-behaviour, whereas $G_2(p)$ contains the properties inherent in sampling. Controllers with $\sum c_i = 1$ have I-behaviour.

The coefficients of the sampled-data-controller are to be chosen so that the step function response of the control loop is nearly a "dead beat response". The pertaining transfer function $F_o(p)$ of the open control loop is derived therefrom and taken as a basis of calculation. With control systems of classes $N \geq 2$ (with $n \leq N$) the described procedure shows good results.

SUBOPTIMAL REGULATION OF SECTION OF HIGH-ORDER, ESPECIALLY TAKING INTO ACCOUNT ALL-PASS PROPERTIES

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In all technical installations the physical variable quantities are subject to certain limitations. In particular the control speed limitation in control engineering should not be disregarded in many cases. As regards the controlled systems discussed, the optimal control produces a process which consists of a switch interval and possesses the smallest control surface, when no overoscillation is admitted. The dependence of these control surfaces on the system parameters is being stated. It is shown that a process consistiting of 2 switch intervals , or of only a single interval, is in many cases very near to the optimal process. The deviation can always be easily determined. The realization of this sub-optimal process with two switch intervals leads to a controller construction which is very near to a proportional-plus-integral-plus-derivative controller. The feedback of the controller will be adjusted, through universal non-linearity, to the limited control speed. The set values of the controller result simply from the characteristics of the controlled system. The system is not sensitive to parameter variations and functions also satisfactorily when there are any disturbances. At a switch interval one obtains the known two-level switch with lagging feedback which, together with the integral regulating element is very near to the linear proportional-plus-integral controller. These controllers are not more expensive than the linear proportional-plus-integral and proportional-plus-integral-plus-derivative controllers, but can replace the latter wherever the controlling process is affected by the control speed limitations. As the technical possibilities of this equipment are utilized to a considerable degree, they can lead to the deliberate admittance of such limitations to a much greater extent, which produces economically more advantageous installations.

THE REDUCTION OF DYNAMIC ERRORS BY MEANS OF DISCONTINUOUS PARAMETER VARIATION

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The purpose of most servomechanisms is to effect the reproduction of some control signal with power gain. Generally, this is accomplished with an error actuated device and this precludes complete equality between input and output under dynamic conditions.

Flugge-Lotz and Wunch suggested a method of reducing dynamic errors by means of discontinuous parameter variation. This was initially developed for second order systems and later extended to third. The present system obtains similar results to those of Flugge-Lotz and Wunch for low order systems, but the new approach readily permits extension to higher order systems.

The paper also reports the experimental application of switched parameter control to an electrically signalled inertially loaded electrohydraulic servomechanism and it is demonstrated that the enhanced response predicted by analogue simulation is obtained. The effects of switching delay are discussed and it is shown that in order to improve the response of high performance systems, severe constraints are imposed on the active components of the controller. Thus mechanical relays are shown to be inadequate and solid state switching circuits developed. With this modification it is possible to improve the response of the whole system by introducing the switching logic in the feedback path. Consideration is given to introducing this logic in the loop around the electrohydraulic valve, but the higher resonant frequencies associated with the lower inertia of its moving parts indicate that an improvement can only be expected by a redesign of the controller to meet the higher speed switching requirements.

As well as a full discussion of these limitations, the paper demonstrates the applicability of the philosophy of control by discontinuous parameter variation to practical nonlinear systems. Both analogue and experimental results for the behaviour of such a system are included.

RECENT RESEARCH ON EFFECTS OF QUANTIZATION IN AUTOMATIC CONTROL SYSTEMS

A. Weirmann

The present work deals mainly with the quantization of signals the amplitude of which lies in the order of variable quantities of few quantization levels. The effects of such two and three-level quantization elements on closed-loop control are being shown.
Priority is given to spectral investigation of multi-level systems with determinental order; they show distinct resonance phenomena with only small amplitude variations.
The investigations are continued of the oscillation conditions of closed-loop control systems in which there are multi-level transfer elements with determinental quantization or with similar signal variations.
The considerations are being finally extended to statistic two and three-level processes which have a special probability distribution for the quantization error, coming from the desired position of the digital controller.
Two practical procedures are mentioned and partially also proved by trial measuring results, which show the substantial reduction or compensation of quantization influence in the stationary state. The cost in technical equipment of the described procedure is very small.

AN OPTIMAL HEATING SYSTEM
By

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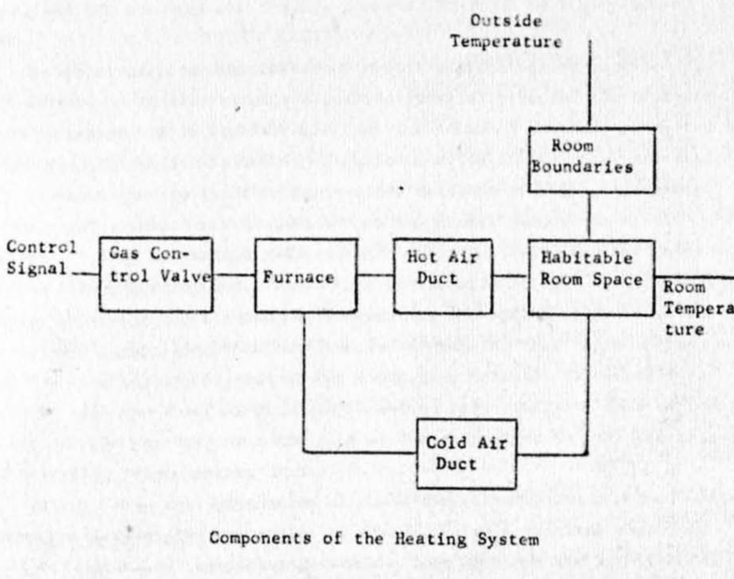
In this paper a mathematical model of the gas-fired forced-air domestic heating system developed previously[1] is used to formulate a method for optimally controlling such system in accordance with a prescribed performance criterion. The optimal problem is one of reducing the room temperature deviation from a prescribed reference value to zero, while at the same time minimizing the value of some predetermined performance or cost functional J. The development of the optimal control law proceeds in essentially four steps. a) Converting the mathematical model to a form which is more suitable for the application of optimization techniques, b) Defining an optimization criterion which incorporates the main objective for minimizing room temperature variations with respect to a prescribed reference temperature, c) Choosing the best optimization technique best suited for the optimization problem, and d) Constructing an optimal control system employing the optimization technique developed. Finally, this optimal system is analyzed, and compared with the conventional heating system using a numerical example.



Components of the Heating System

MULTIDIMENSIONAL EXTRAPOLATION FOR OPTIMAL CONTROL AND DESIGNING

L.A. Rastrigin, V.S. Trahktenberg

The change of situation during a system design process as well as the parameter drift of controled object lead to repeated realization computations in order to describe optimal parameters of a system or control. Such a way of following the changes of situations is not rational and leads to considerable elongation of the design periods or to the reduction of effectiveness and control operativeness.

An algorithm of usage of information, which is stored as a result of completed optimality computations, for an estimation of optimal parameters in following new situations, is worked out. The basis for the estimation is a very limited learning sequence without carrying out a procedure of multiparametric optimization.

Theoretical investigation of recovery errors of simple linear and nonlinear functions is realized by means of multidimensional linear extrapolation method. The investigation of recovery error of a complex linear function have been done, using electronic computer, through estimation of a polynomial coefficients which approximates the given function in a best way. The values of the function are known for some points of observation intervals; the number of such points is less than the degree of approximated polynomial.

The multidimensional extrapolation method is applicable for searchless parameter tuning of a selfadaptive model in a problem of object identification. As a situation defining the object state, either an autocorrelation object output function ar a mutual correlation input and output object function is chosen. Experiments, concerned with model parameter determination using the multidimensional extrapolation method were performed by means of electronic computer for theoretical and choice correlation functions. The experiments have shown good results in the sence of proximity of the predicted model with the theoretically optimal one.

MINIMUM VARIANCE ESTIMATION OF PARAMETERS AND STATES IN NUCLEAR POWER SYSTEMS

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Experimental identification of dynamic characteristics of nuclear reactor systems by current methods, such as 1/e period measurements or transfer measurements via control rod oscillations or random noise inputs, are limited by one or more of the following:

(1) a capability of giving information about only a few isolated parameters,

(2) an inability to deal with the basic nonlinearities of nuclear systems,

(3) a long experimental running time which prohibits monitoring dynamic characteristic changes which frequently occur, and

(4) a need for highly specialized equipment for producing a particular system input.

In this paper, a minimum variance sequential estimation procedure is shown to be capable of bypassing these limitations. This procedure estimates a system's dynamics parameters using measurements of the system output from an arbitrary known input.

Results are presented from the actual experimental application of the procedure to three reactor systems - the EBWR (Experimental Boiling Water Reactor) and EBR-II (Experimental Breeder Reactor - II) power reactors and the PUR-I (Purdue University - I) research reactor. In the EBWR experimental application, the parameter estimates were based on simultaneous measurements of power and pressure during rod drop transients. This estimation was repeated in six different power ranges to determine the parameters as a function of power. The procedure was successful in obtaining parameter estimates which were physically reasonable and also gave, for both power and pressure, a good agreement between the model predicted transients and measured transients. Although less extensive, the additional applications to the EBR-II and PUR-I reactor types demonstrate the broad range of identification problems which may be solved using this procedure.

STATE IDENTIFICATION OF A CLASS OF LINEAR DISTRIBUTED SYSTEMS

by

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This paper is concerned with the state identification problem for a class of linear distributed parameter systems. Since the system is described by a partial differential equation, its solution requires knowledge of initial conditions and environment forcing terms which include the boundary conditions. The problem studied here is the following: Given i) inexact measurements of the initial conditions and environmental interactions ii) inexact and possibly incomplete measurements of the state of the system, determine on the basis of the above data the true initial and boundary conditions associated with a given partial differential equation which is in some sense optimal with respect to the given data.

The basis for selecting the estimates of the boundary and initial conditions associated with a given partial differential equation, that is, the criterion of optimality, is that of "least squares". Theoretical results as well as a computational scheme with numerical results are presented.

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MEASUREMENT OPTIMIZATION IN BATCH PROCESS OPTIMAL CONTROL

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In connection with the direct digital control for batch processes, the optimum timing of the measurements has been pursued to reduce the required number and the precision of the measurements. This paper shows that the optimum timing is strongly influenced not only by the process constant, the form of the cost function and its parameter, but also by the precision of measurements and the disturbance signal to the process. The cost functions (control performances) which consist of quadratic in the control and terminal error or steady state error are evaluated by the use of the linear estimation theory and stochastic optimization technique.

The discussions are divided into the transient state optimization, that is, the terminal control problem, and the steady state optimization. In the former case, if the measurement is single and the process is disturbed by random noise, it is seen that for a stable process having short time constant the optimum timing approaches to the terminal time asymptotically and for a very unstable process it approaches to the middle of the control interval. For a stable process, the optimum timing is to be near the terminal time when the initial uncertainty is negligible and the timing becomes earlier when the initial uncertainty is present.

It is required more than one measurement to achieve the steady state optimization and the optimum timing of measurements subject to external disturbances has almost uniform intervals. This paper presents a compromise between the number and the precision of measurements for some specified performance to reduce the total measurement cost as to both stable and unstable processes.

These discussions have rather general nature and include not only the stable process but the unstable one such as fermentation processes or nuclear reactors and may be applied to the measurement optimization for multivariable processes.

OBSERVABILITY OF LINEAR DYNAMIC MEASURING SYSTEM

AND SOME APPLICATIONS

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If we can not assume that the response speed of a measuring device or transmitter is large enough to be ignored in comparison with the change of the measuring values(input values to the measuring device or transmitter), we must treat this measuring system as the dynamic measering system.

In this case the relation between input and output values is described by differential or difference equations.

Observability on such a system is an extension of Kalman's State Observability and equivalent to the Input Observability.

In this paper, sufficient conditions and necessary conditions are obtained in the form of Theorem together with Corollary for the discrete-time systems, the continuous-time systems and the time-varying systems respectively. After that some applications to the concrete problems such as measurement of dynamic or transient motor torque by use of strain meter are discussed with experiments.

IDENTIFICATION OF THE PARAMETERS OF A TIDAL CHANNEL FROM SIMULATION AND OTHER APPROACHES

by

Shri K.K.Bandyopadhyay [x]

and

Dr.S.Dasgupta [xx]

A tidal river is a large scale nonlinear physical system with time varying distributed parameters. This paper discusses the determination of some of its important parameters for first order approximation. The identification has been achieved from /a/ analog simulation, /b/ phasor diagram as well as /c/ input - output relationship approaches.

An instrumentation scheme of the analog set up for the parameter identification has been given.

Example has been derived from the River Hooghly of India

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"Delayed Action Control Problems"

by

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and

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In this paper we indicate modifications to be made in the theory of optimal control when the controlled system model has dependence on both the previous history of state variables and control variables. More specifically, we consider systems which are modeled by linear functional differential equations. The systems may have additional side constraints or multiple cost functionals. The question of the existence of an optimal controller is studied, and the necessary and sufficient conditions for an optimal controller are derived.

OPTIMUM CONTROL OF LINEAR TIME-LAG PROCESSES
WITH QUADRATIC PERFORMANCE INDEXES

by

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A theory of optimum control for processes described by linear differential-difference equations of retarded type, with quadratic performance indexes, is presented. Basing upon the maximum principle, the problem is reduced to Fredholm integral equation of the second kind. By application of Fredholm theory the following facts are established: the existence and uniqueness of solutions, the general form of optimum control for various situations /for open - and closed-loop systems, predicted control/, its linearity with respect to process complete state and number of other nontrivial properties. Existence of some matrix kernel supplying full analytic solution to the problem is demonstrated. Integral equations and Riccati matrix differential equation for this kernel are derived.

Number of essential analogies to well known Kalman state regulator problem are shown. For linear processes without delays the results presented reduce strictly to Kalman results, giving some new insight.

On the basis of these results new computational algorithms can be developed.

ON BOUNDS OF PERFORMANCE MEASURE AND MIN-MAX CONTROLLERS

IN TIME-LAG SYSTEMS*

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When a system is subject to bounded disturbances, the value of the performance index deviates from the nominal one. The upper and lower bounds of the performance index for the time-lag system can be determined by the application of the optimum control theory. Such bounds establish a good measure of the influence of possible disturbances acting on the system. Since the optimal feedback control can rarely be determined for time-lag systems, an approximately optimal controller that operates on the current state and/or delayed state variables offers a practical solution. Such controllers can be designed on the basis of min-max criterion. A procedure for the design is presented. The presentation is illustrated by examples.

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**Formerly Koivuniemi.

OPTIMAL DISCRETE CONTROL OF TIME LAG SYSTEMS

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The optimal piecewise constant control of time lag systems with time-varying delays in state and control is investigated. The case of a delay in state only is considered first; a Hamiltonian type functional and a co-state system, which include the time dependence of the delay, are defined; the delay in state $\theta(t)$ is assumed to satisfy $\theta(t) \geq 0$ and $0 \leq \dot{\theta}(t) < 1$ for $t_{initial} \leq t \leq t_{final}$.

Local necessary conditions are found for the optimal control of systems which are not necessarily linear; one such condition is that the Hamiltonian is a local maximum or stationary with respect to the optimal control. A maximum principle is formulated for linear time lag systems with a quadratic index of performance; in this case, the Hamiltonian must be a global maximum with respect to the optimal control.

The necessary conditions for system optimality are modified when the system is allowed to have a time-varying delay in control in addition to the delay in state.

An analytic example is given to illustrate the theory. It points out some of the difficulties encountered in the solution of optimal control problems with time-varying delays.

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ON THE THEORY OF OPTIMAL CONTROL WITH BOUNDED PHASE COORDINATES

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Sverdlovsk
U S S R

The report deals with certain problems of optimal control in linear systems with bounded state-space variables, by an approach based on the methods of functional analysis. It is thus possible to indicate the necessary and sufficient conditions for the solvability of the problems concerned, as well as to obtain an additional information on the functional Lagrange multipliers. The approach also indicates certain means of tackling the boundary-value problem and computing the optimal control in case of singularities in the maximum principle. The given methods may also be applied to a class of related problems with infinite-dimensional properties, such, in particular, as the general terminal problem in systems with time-lags or the problem of minimizing the extremal value of a function of the phase coordinates.

FINDING OF INITIAL VALUES OF THE AUXILIARY VARIABLES IN OPTIMAL CONTROL OF A CLASS OF LINEAR SYSTEMS

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Summary

A precise solution to one of the basic problems in the optimal control theory is given in this paper: finding out of an initial vector $\bar{\varphi}(0)$ for the auxiliary system, defining the optimal high-speed control of an important class of linear plants by means of the maximum principle.

The solution is built in stages. In the first stage the breaking (switching) moments $t_1, t_2, \dots, t_\ell$ of the optimal control are considered as parameters satisfying the condition $0 < t_1 < t_2 < \dots < t_\ell$

The space $\mathcal{T}^*$ consisting of initial vectors $\bar{\varphi}(0)$ is divided into n non-intersecting subsets $\mathcal{T}_\ell^*\ (\ell = 0, 1, 2, \dots n-1)$. For each $\ell = 0, 1, 2, \dots, n-1$ the corresponding subset $\mathcal{T}_\ell^*$ consists of all initial $\bar{\varphi}(0)$, for which the optimal control has ℓ breaking (switching) points.

Proposition 1 defines the exact kind of $\mathcal{T}_\ell^*$.

In the second stage it is shown as to how $t_1, t_2, \dots t_\ell$ can be found. One of the $2n$ transcendental systems deduced, connects the breaking moments of the optimal control and the initial state $\bar{x}^*$ of the controlled plant in analytic dependencies. The precise solution of the problem considered is formulated by Proposition 2 and Lemma 3.

NATURAL OSCILLATIONS OF PNEUMATIC POWER AMPLIFIERS AND A SOLUTION FOR THEIR ELIMINATION

by

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There is a pneumatic amplifier - based on the well-known force-balance - generally used all over the world which is discussed in this paper. There was a paper at the IFAC Congress in 1966, dealing with the results of theoretical investigation of self-sustained oscillations by a similar type of amplifier. Opposite to this mechanical procedure for the damping of oscillations described in the foresaid paper, our work introduces a pneumatical solution of the problem.

It is possible to find a set of pneumatical R-C members to the own parameters of the amplifier, on using of which the self-sustained oscillation is not able to develop itself. Because of the well-known non-linearity of the pneumatical base-members /R and C/, these parameters are to be specified by way of experiment only.

The paper gives the main results and also a short survey about the methods of study.

DYNAMIC BEHAVIOUR OF HYDRAULIC COMPONENTS

by

J.J. Hunter

In order to make realistic studies of hydraulic systems on analoque or digital computers, models of hydraulic components which are based on experimental investigations are necessary. Most information now available is limited to steady state characteristics so that control studies on hydraulic systems have tended to be mainly theoretical. The absence of experimental results of the dynamic behaviour of hydraulic components has thus impeded the application of control theory of hydraulic systems.

Some results of investigations made on a water hydraulic frequency response rigeare presented for various hydraulic components including flowmeters. As these components are generally non-linear, transfer functions between flow and other variables are obtained by superimposing a small sinusodial variation on the mean flowrate and measuring the amplitude and phase of the other variables relative to the flowrate. The frequency range of the test rig is from 0.01 to 100 Hz and the mean flowrange from 1 to 9 x 10^{-3} m^3/s. The modulating wave form is not restricted to the sinusodial Other waveforms can be used to compare with computer simulation studies using the derived model. Details are given of the design and tests of the transient flowmeter designed for this work, which has a frequency response extending up to about 300 Hz. Its behaviour has been examined with rapidly changing flows. Its mean indicated flowrate, under these conditions, is in good agreement with the average flow by measuring the total mass flow over a measured interval of time. Some problems encountered in the design of the test rig and in the 'noise' inherent in the normally turbulent flow regime of water hydraulic circuits will also be discussed.

SMALL AMPLITUDE RESPONSE CHARACTERISTICS IN HYDRAULIC SERVO MECHANISMS

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A. Lichtarowicz B.Sc., Ph.D., C.Eng., M.I.Mech.E.

Apart from development testing and a few extreme conditions, a servo system spends most of its life dealing with small excursions. These may be so small that non-linear effects become of the same order as command signals. In this paper an attempt is made to study the behaviour of hydraulic servomechanisms operating in this region by the theoretical analysis of the equations of the system.

A digital computer is used to analyse the performance of the system and the results are applicable generally since the equations and results are presented in dimensionless form.

The results, presented graphically, indicate the trend of performance as the input to the system is reduced and studies the effects of viscous damping, leakage, and seal friction. Normal analysis of such systems assumes a linear valve characteristic, however the paper draws comparisons between this approach and a more realistic representation of the displacement flow curve.

It is shown that after a certain level of input, even the inherent valve damping characteristic breaks down and the system exhibits a continuous small amplitude oscillation.

REDUNDANT ELECTROHYDRAULIC SERVOACTUATORS

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Current design approaches for achieving continued servoactuator operation in the presence of functional failures are described. Examples and supporting data are drawn from various aerospace applications.

MECHANICAL TRANSMISSION RATIO REQUIREMENTS IN MINIMUM-TIME POSITIONING SERVOS

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[illegible] Inc.

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Many industrial positioning drives and servomechanisms today are required to operate in a minimum-time mode. For these drives, care must be exercised in selecting the mechanical transmission connecting the driver and the load lest the positioning time will degrade. Equations and charts are presented to facilitate this design problem. The loads are assumed to be inertial in nature; the drivers are of the servomotor type and the motor-clutch type. Conventionally, the transmission ratio is selected by load matching, which gives a maximum load acceleration; it is shown that this practice in general does not give a minimum-time performance for the types of drivers and loads considered.

Experimental methods of sizing control valves for technological processes

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Department of the technology of automatic control,
German Democratic Republic

With the corrective flows of technological processes it is often impossible to predict the data required for the control valve sizing with sufficient accuracy. This may for example be traced back to inaccuracies in calculating the heat engineering of the process or in calculating the pressure drop of lines. For the injection of water for the temperature control of superheated steam in power plants as a typical example of a corrective flow by way of a calculation of errors the inaccuracy of the predicted flow and the pressure drop on the control valve is shown to be 100%.

In such cases the matching of the control valves in accord with the test results is inevitable. A method is developed to iteratively adapt the control valves with the aid of a chart including a logarithmic plot of the flow and pressure drop (Δp-Q-diagram). The chart is experimentally recorded by means of a special plotter on the plant equipped with a temporary control valve. From this measuring chart the necessary size and appropriate flow characteristic of the control valve can be determined.

Experimentally recorded Δp-Q-charts of a water injection valve of a power plant and a pressure control valve of a steam heating plant demonstrate the application of the method.

Special problems arising while determining the operational flow characteristic under flow-independent pressure changes are discussed.

"Investigation of Dynamic Behaviours of Controlled Thyristor Electric Drives"

by

A.A.EFENDIZADE, B.A.LISTENGARTEN, S.M.BAGIROV,
T.A.ZAIROVA, and Y.M.KURDUKOV

The behaviours of the induction motor fed by a variable frequency converter have been treated. The plot of the frequency converter voltage with an intermediate D.C. supply has the appearance of staircase waveform, and hence the "Converter-Motor" system may be considered as a sampled-datd system consisting of a Zero-order hold and linear plant corresponding to the equivalent circuit of the induction motor.

Based on the theory of sampled-data system the quasi-stationary and electromagnetic transient processes have been studied. An analysis of the motor starting conditions has been performed at different frequencies and under load for both the sine and the staircase waveform of the output voltage.

A closed-loop system of automatic speed control of induction motor has been developed and studied with the motor being operated from a static frequency converter at a constant load power.

A calculation procedure is presented wich has been used to evaluate the electromechanical transient process in an induction motor with the latter being fed from a static frequency converter provided with a three-phase parallel inverter. To perform computations with the use of an electronic digital computer the equations for the induction motor are presented in a system of variable-speed axes.

The voltages applied to the motor are presented analytically in the form of staircase functions.

A D.C. thyristor electric drive system with a three-phase half-controlled rectifier has been developed and investigated. This system is intended for the rimming machines used in tyre manufacturing plants.

SYSTEM OF AUTOMATIC GOVERNING THE CONDITION OF ABSOLUTE SLIP CONSTANCY OF AN INDUCTION DRIVE WITH TIRISTOR CONVERTER CONTROLLED FREQUENCY

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Summary

The system to be considered consists of closed circuits for rgeulation of voltage, frequency and condenser capacity of the converter.

The converter voltage is regulated according to deviation of absolute slip of the motor from a given value in dependence upon frequency, load and condenser capacity. The value of absolute slip is measured by discrete deduction of proportional motor rotation velocity frequency from master generator frequemcy of the converter with following conversion into feedback voltage.

In addition to elimination of dead zone and decrease of inertia in the system at time of switching, the active resistance to be switched between rectifier and inverter by decreasing the number of doubling pulses to a single one allows to simplify tiristor arrangements for control of rectifier and inverter bridge circuits.

The contactless tiristor protection of the system against excess currents arising from abnormal conditions being peculiar to the given system, is based upon the principle of control normal tiristor action, protection against sustained vibrations is carried out by introduction of an elastic feedback in the form of a short circuit in the smoothing choke.

Investigations of developped units of automation- control- and protection systems have given results, proving their workability and the possibility for practical use of the system under consideration.

ON THE THEORY OF CONCERNING PROBLEMS INVARIANT SERVOSYSTEMS WITH THE THYRISTOR VARIABLE FREQUENCY CONTROL BY SQUIRREL-CAGE 3 - PHASE INDUCTION MOTORS

W.H. Javorsky, E.S. Avatkov, W.I. Makshanov, E.V. Aldonyn, V.K. Dorokhin

This paper discusses theory of servodrives which possesses in compaison with now widespreaded serwordrives with three rotating mashines the fast twice grater efficiency and essential greater reliability. The absence of engineer calculation methods bampers the elaboration of such a progressives, but complicateds, non-linears impulse serwodrives. The paper states one of engineer calculation methods, which ensures high stability and sufficiently precise shadowing. With assistance of invariant inputs of disturbence moments may be compensate the influence of variable part of object inertia moments at serwodrives dynamics. With assistance of "nonlinear isolated functions" it is possible to form the differential equations for dynamics of nonlinear and linear variantes and essential reduces the labour-consuming for calculation. Paper gives extracts of servodrive calculation with 10 kw-motors, for which the type equations utilized baen. Calculation demonstrates expediency of methods paper discussed.

SPEED CONTROL OF INDUCTION MOTORS USING SELF-CONTROLLED THYRISTOR INVERTERS

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In the static scherbius system, the rotating speed of an induction motor is controlled by rotor power feedback to the power source through the silicon rectifier and thyristor inverter in its secondary circuit.

The authors analized the power flow in the induction motor with secondary excitation, and get the conclusion that not only the lower speed region below the synchronous speed, but also the higher speed region above the synchronous speed would be possible using the self-controlled thyristor inverter instead of the silicon rectifier in the ordinary static scherbius system.

In this newly developped system, the secondary power is added to the primary power to get the super-synchronous drive. Also the regenerative braking in normal speed region becomes possible which is impossible in the ordinary scherbius system.

To realize the super-synchronous scherbius system (SSSS), the current type self-controlled inverter, which is operated in accordance with the secondary induced voltage, should be used. This allows bi-directional power flow through the converter. The high frequency modulated distriбutor is adopted in the experimental equipment to detect the phase relationship of the secondary voltage and give the gating signal to the thyristor converter.

The experiment resulted in the stable operation in wide speed region both above and below the synchronous speed and proved the analysis very well.

INTEGRATED DIGITAL CONTROL OF A D.C. THYRISTOR DRIVE

F. Fallside and R.D. Jackson

A computer controlled DC machine drive is described in which each thyristor in the output power amplifier is directly under the control of the computer. This technique gives a precise control of the firing instants and is well suited to the requirements of optimal control. It also allows the use of simple firing circuits since these are triggered directly from the accumulator of the computer, and the reduction of external logic circuits since their functions can be absorbed by the computer.

In the experimental drive a 2 HP motor is fed from a three phase bridge thyristor amplifier. The control computer has a 12 bit word length and precise speed control is obtained by sampling shaft angular position. A digital shaft encoder is sampled by the computer at 300 Hz, the thyristor repetition frequency, and the thyristor firing delay computed from the increments of position and a programmed reference. The correct firing instant for the current thyristor is computed and the thyristor is fired by the computer; the process is then repeated for the next thyristor.

In addition to the experimental results a full description is given of the control algorithm together with the methods adopted for synchronising the firing pulses with the 50 Hz amplifier excitation and other practical details.

DEVELOPMENT OF INDUCTION MICROMACHINES CONTROL METHODS

D.V. Svecharnik, L.H. Shidlovich, Yu.M. Kelim
A.A. Beloglazov

This paper deals with arrangements and principle of motosynes and motors action controlled by space displacement of winding axis. Shown are great possibilities of motosynes, from control point of view.

Making three-phase winding on stator and internal rotor, we can obtain different ways of control by changing this or other parameter:

a/ voltage magnitude/signal coefficient/,

b/ time voltage phase, fed to the windings,

c/ location of resultant axis of three-phase windings,

d/ space angles of rotor and stator rotation.

In the result, 63 control methods can be obtained instead of normally used in motors: amplitude, phase and amplitude-phase methods.

The main problems in designing of micromotors theory and methods are shown too. Shown are formulas for start-up moments in regular and differential motosynes. Interchangebility of the motor which is controlled by space displacement of winding axis, what happens to be a frequent case with motosynes, is compared and investigated. Calculated are meanings for direct and back sequenticility of motor. Similarity of calculated and experimental characteristics is absolutly sufficient for engineering calculations.

Shown are cases of utilization of motors controlled by: space displacement of winding axis, synchro-motosyn transmissions with moment strenghtening, actuator of electromechanical manipulators. Shown are technical characteristics of discussed motors controlled by winding axis space displacemement.

TRANSIENT AND STEADY STATE ANALYSIS OF THE STEPPING MOTOR

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Equivalent circuit and equations for calculating the performance of a reluctance type stepping motor, its performance limitations, and a method for driving it as a high torque to inerta servomotor for continuous position control are developed.

NEW KIND OF SYNCHRONOUS MICROMOTOR

Jerzy Owczarek, Warsaw Polytechnical Institute, Poland

The paper deals with theory and calculation way of a new kind of synchronous micromotor. The principle of operation of the micromotor is based on the phenomena which take place in hysteresis motors, magnetoelectric motors and electromagnetic excitated synchronous motors.

Due to suitable magnetic materials used in the construction and due to genuine method of start of the motor, better operational parameters in compare with the other synchronous motors, at giver range of power, are obtained. Additionally, the construction of this micromotor is simpler and its production is easier than the same of any other sort of synchronous micromotors.

Some models of these micromotors having various technical data, have been made. Tests of these models has confirmed the validity and precision of the theory and given way of calculation.

FACTORS INVOLVED IN THE ANALYSIS AND DESIGN OF D.C. LINEAR ACTUATORS

by

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U.C.N.W.,
Bangor,
U.K.

This paper is concerned with the design and construction of direct current motors capable of producing thrust and motion in a straight line. Such devices of this nature may be employed as actuators and retain the variety of force/velocity characteristics common to d.c. machines.

Two forms of linear construction and the principle of operation are described in the paper. The problems of flux leakage introduced by the discontinuities in the field system at the terminal poles is discussed in relation to these configurations.

Finite difference approximations to the field equations are employed in an iterative procedure to obtain the flux density distribution throughout the machine under given conditions of excitation. This information enables the thrust to be calculated and the extent of the leakage fields to be determined. Optimisation of the machine topography and quantities such as thrust/weight or thrust/input power become possible.

An arrangement is briefly described by which output movement is limited to short strokes enabling an encapsulated armature to be used without the necessity of a commutator or brushes. A typical application of such a device is the operation of mechanical valves, where it is desired to eliminate the need for gears.

DIFFERENTIAL DYNAMIC PROGRAMMING

D.H. Jacobson and D.Q. Mayne

In this paper several new second order algorithms for optimising non-linear systems are described. The original differential dynamic programming algorithm, permitting only small changes in the control at each iteration, is superior both in the number of differential equations to be integrated and in convergence to conventional second variation algorithms. By permitting global variations in control and using a new step-size adjustment method, a class of powerful algorithms is obtained, possessing several advantages. H_{uu} on the nominal trajectory is no longer required to be positive definite and the algorithm can deal with control constraints and, in particular, bang-bang control problems. Several examples are given to illustrate the algorithms, and the application of the algorithm to stochastic problems is also discussed.

THE OPTIMIZATION OF DYNAMICAL SYSTEMS

S. de Julio

A new technique for the approximate computation of optimal controls is presented, which avoids the need to solve the differential equation governing the behavior of the system. The technique is shown to be applicable to linear systems governed by partial differential equations when the cost functionals are quadratic.

Paragraphs 2 and 3 deal with the case of distributed control, i.e. when the system equation is of the type

$$\dot{x} = Ax + Bu \qquad x(0) = x_o \tag{1}$$

In § 2 it is supposed that the desired state evolution is assigned and the cost functional to be minimized is

$$J(u;x) = \int_0^T ||x(t)-x_d(t)||^2 dt + \lambda\int_0^T ||u(t)||^2 dt \tag{2}$$

whereas in § 3 only the desired final state x_d is given and the criterion is

$$J(u;x) = ||x(T)-x_d||^2 + \lambda\int_0^T ||u(t)||^2 dt \tag{3}$$

In both cases an approximate solution to the optimization problem is shown to be given by the solution of the ε-problem, defined as the minimization of the functional

$$J_\varepsilon(u;x) = J(u;x) + \frac{1}{\varepsilon}\int_0^T ||\dot{x}(t)-Ax(t)-Bu(t)||^2 dt$$

§ 4 deals with the boundary control problem for which the system equation is

$$\begin{aligned} &\dot{x} = Ax \qquad x(0) = x_o \\ &x|_\Sigma = u \end{aligned} \tag{4}$$

$x|_\Sigma$ being the restriction of x to the boundary. The ε-problem for this case is that of minimizing the functional

$$J_\varepsilon(u;x) = J(u;x) + \frac{1}{\varepsilon}\int_0^T ||\dot{x}(t)-Ax(t)||^2 dt$$

subject to $x|_\Sigma = u$, where $J(u;x)$ is either (2) or (3).

The results of the computation of a minimal norm control for a distriubuted parameter system are reported in § 5. In § 6 it is pointed out that the proposed technique can be extended to a broader class of systems and cost functionals.

A STATISTICAL APPROACH TO THE OPTIMIZATION OF THE CONTROL SYSTEMS WITH MULTI-PEAK PERFORMANCE INDEX

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It has been very difficult to optimize the poorly defined systems with multi-peak performance index by means of the conventional method such as gradient or trial one. But in some cases of the quasi-stationary process where the performance index (PI) is almost explicitely independent of time, there seems to be a correlation, more or less, between the optimum and suboptimum points. It is also expected that we can utilize, for the detection of the correlation, some of the measurable quantities that depend on the disturbances in different forms from the PI function.

In the method presented here, using the above properties, the system records the sets of data such as the optimum point, the suboptimum point, their PI values and other useful correlating quantities, during the exploring period. Then the system determines by the minimax probability ratio test whether to be able to predict the global optimum point from the operating locally optimum point, or to continue the exploration, where the power of test is determined so that the expectation of the loss consisting of the cost of the global exploration and the risk due to the incorrect decision may be minimized. The simulation results as well as analytical results show that the expectation of the loss is fairly much reduced if any correlation as mentioned above is available.

For such systems as require much exploration time for a scanning comparing with the change rate of the state of the system, a modified tentative method is also proposed.

A SURVEY OF SOME RECENT ITERATIVE TECHNIQUES FOR COMPUTING OPTIMAL CONTROL SIGNALS

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This paper will present a survey of the davidon and conjugate gradient iterative method for minimization. Various properties of these techniques are discussed and their application to properties of optimal control are indicated. Two examples illustrating these methods are also included.

CONVERGENCE PROOFS FOR A DYNAMIC-PROGRAMMING SUCCESSIVE-APPROXIMATIONS TECHNIQUE

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A dynamic programming successive approximations technique has been suggested by Bellman and used successfully by a number of authors. In the case where there are as many control variables as state variables, the technique reduces an n-dimensional problem to the solution of a sequence of one-dimensional problems. This paper presents proofs that the method converges to the true optimum solution for three important classes of optimal control problems, all of which are related to certain convex programming problems.

This research was sponsored by and performed at the Information and Control Laboratory of Stanford Research Institute, Menlo Park, California 94025.

"Identification of process trough the minimalization distance between signal collections"

S. Węgrzyn, G. Denis,
J. Delisle

In this papper we show one off possible solution of identification problem trough the minimalization distance between signal collections. This method gives a general algorithm of identification 8 . In the case of Euclidean spaces is possible to give an analytic solution of this algorithm 15 ; in the case of another spaces we can find solution of this algorithm in the numerical form. We show, in what kind we can consider nonlinearity and transport delay in identification process, which are the most important phenomenon for models of industry process.

DESIGN OF MODEL FOLLOWING SYSTEMS USING THE COMPANION TRANSFORMATION

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and

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A new approach is presented for the design of single input, linear, time-invariant model following systems. The performance index to be minimized is the norm of the difference between the model and system companion transformations, with the constraint that the system and model eigenvalues are the same. This constrained minimization is converted to an unconstrained algebraic minimization by including state feedback in the controller. Since no iterative solutions of the differential equations are required, the solution time is much less than that required for approaches to this problem involving minimization of an integral performance index. The motivation for the new method is discussed, and an example demonstrates how the approach can lead to a fast solution of model following problems.

DETERMINATION OF MODELS FOR IDENTIFICATION WITH QUALITY CHARACTERISTIC IN THE TIME DOMAIN

by

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Methods are being described for the investigation of characteristic values or system identification for linear analogous systems with one input and one output, which are related to single or multiple integrals of signal functions. Well-know methods from the function analysis, which concern linear standardized spaces, are applied. It is essential that when there is a rational transfer function of the models one should not proceed from the differential equation but from the appropriate integral equation. With using the norm according to Chebyshev and the error square method, definite methods for digital computers /including the method for numerical processes/ are presented, and for each procedure examples are given, which allow for a first insight in the efficiency of the method.

ORDER AND FACTORIZATION OF THE IMPULSE-RESPONSE MATRIX

In this paper is considered the problem of calculating the order of a linear system described by the impulse response matrix, as well as that of the factorization of this matrix.

A method for the construction of sets of solutions of the class of homogeneous differential equations associated with the impulse response matrix, starting from the latter, is used as a basis for resolving these two problems. This method consists in carrying out operations of convolution between the impulse response matrix and functions belonging to the space of input functions. It is also shown that it is possible to choose suitable sets of input functions, and the sets of solutions obtained are such as to contain fundamental sets.

The evaluation of the dimensions of these sets therefore resolves the problem of the calculation of the order. This can be carried out in a simple way by using the properties of the Wronskian matrix of a fundamental set of solutions of a differential equation. The practical construction of a set of solutions and the choice of a fundamental set resolves the problem of factorization.

This general method is applied both to continuous and discrete time systems, as well as to time invariant and time varying systems.

By proceding in this manner the most effective algorithm for the calculation of the order of a time invariant system can be deduced. In addition it is possible to give several variants of the above-mentioned algorithms and new algorithms for the time varying case. Finally it is possible to arrive at new solutions for the problem of factorization.

C. BRUNI - A.ISIDORI- A.RUBERTI

ON THE NUMERICAL CONSTRUCTION OF LIAPUNOV'S FUNCTIONS

by

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Abstract. A new method for the numerical construction of Liapunov functions $v = \varphi(x)$ is presented. This method is not based upon the classical theorems of Liapunov, but on the new extension theorems recently proved by N.P. Bhatia, G.P. Szegö and G. Treccani. These extension theorems do not impose any sign-condition on the functions $\varphi(x)$. The method developed allows to approximate the region of attraction $A(\{o\})$ of the equilibrium point $x = o$ on an n-th order dynamical system: $\dot{x} = f(x)$, $f(o) = o$, by means of nonhomogeneous polynomial forms $\pi_m(x)$ of arbitrary degree m. In addition it allows to distinguish three different situations: the case in which $A(\{o\})$ is the whole space, the case in which $\overline{A(\{o\})}$ is not compact and the one in which $\overline{A(\{o\})}$ is compact. In addition one obtains two parameters which are quite useful in the final interpretation of the results, the radiuses of the smallest circumscribed and of the largest inscribed sphere relative to the level surface of $\varphi(x)$ which approximates the boundary of $A(\{o\})$. Numerically, the problem is presented as an unconstrained max-min problem over the coefficients of $\pi_m(x)$ of a suitable functional derived by the method of penality functions. The algorithms of Davidon-Mc Gill, Powell and the golden section one-dimensional search are applied.
A complete program in Fortran IV is available and an example is worked out completely.

FINITE-TIME STABILITY IN CONTROL SYSTEM SYNTHESIS

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Definitions of various types of finite-time stability are presented. Also, theorems are developed which appear to be of practical use in the synthesis of control laws which guarantee finite-time stability for systems governed by ordinary differential equations in which the control enters linearly. Given that the initial state belongs to a specific set, conditions are established which are sufficient to guarantee the state belongs to a given set for a specified interval of time. The control may be selected in such a way as to satisfy these conditions. Selection of such a control is discussed, and illustrative examples are presented.

STABILITY OF RELAY CONTROL SYSTEMS

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The stability of relay control systems with linear switching functions is investigated by means of exact piece-wise linear calculations. It is found that when the plant consists of three integrators the system is unstable in-the-large for all values of the controller coefficients.

APPROXIMATE DETERMINATION OF THE STABILITY DOMAIN FOR NONLINEAR SYSTEMS

Eugenio Sarti [*]

The work deals with a method to approximate the stability domain R of nonlinear systems, such that the origin in the state space is an equilibrium condition. A first kind of approximation is obtained by considering a subset S of R, that is bounded by a Liapunov hypersurface: such a subset is a locus of trajectories converging to the origin while time increases. A Liapunov function of the type "a quadratic form plus an integral of the nonlinearity" is used to define a subset S for a class of systems with one nonlinear element, the characteristic of which leaves the absolute stability sector for some values of its input variable. The geometric properties of the bounding hypersurface are investigated.

A set T of initial conditions, beginning from which the state of the nonlinear system converges to the origin, is another approximation of the domain R. Unlike the set S, from which the trajectories cannot go out, the state of the system can leave a set T: i.e., to belong to a set T is a weaker condition then to a set S. This one enables us to find regions T bounded by a particularly simple hypersurface, which does not depend upon the nonlinear characteristic. From this point of view we can consider the method as an extension of the notion of absolute stability to systems that are locally, but not globally stable.

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THE CONSTRUCTION AND USE OF LIAPUNOV FUNCTIONALS.

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Following the pioneering work of A.A.Movchan the second method of Liapunov has been used recently with some success in a variety of stability analysis of distributed parameter systems, that is dynamical systems described by partial differential equations.

This paper will first review the basic concepts and theorems and then discuss methods of constructing Liapunov functionals and metrics for the stability analysis of systems governed by second order hyperbolic and parabolic operators. Functionals for a wider class of linear operators may be obtained by generalising the construction procedure for second order operators. For a non-linear problem functionals may be found by modifying the functionals for the linearised problem.

The techniques described in the first part of the paper will then be illustrated by the following examples drawn from the fields of vibration and closed loop control:

(i) vibrations of a damped rotating shaft,
(ii) control of temperature in a uniform bar,
(iii) angular position control of a heavy uniform shaft flexible in torsion,
(iv) normal acceleration control in a flexible missile.

The paper will conclude by mentioning other possible applications of the Liapunov functional method and areas for future research.

REMARKS ABOUT THE METHOD OF ASSOCIATED LINEAR SYSTEMS

O. Palusiński, A. Laurens,
M. Gauvrit

This paper deals with some results on the stability of two important classes of non-linear systems, obtained in a Ljapunov's second method. These stability conditions show that, for these systems, the hypothesis of linear associated systems is quite feasible ((1), (2), (3)).

These two classes are, on one hand, the class of feedback control systems exhibitivy a linear plant and an element with non-linear static characteristic, on the other hand, the class of non-linear systems described by a second order differential matrix equation. The choice of Ljapunov functions has been dictated by energetic considerations.

ELEMENTS OF INTERNATIONAL CONTROL THEORY

Ya. Z. Tsypkin, G.K. Kelmans,
L.Ye. Epstein

Learning automatic systems have a disposition to improve their behaviour /and property/ in the performance process. In this paper, the design principle of learning automatic systems is discussed. Possibilities and special features of such systems are also explained.

The function of learning automatic systems is based upon learning algorithms of observed situation classifications /images/.

Peculiarities and complexity of situation classification are defined, to a great extend, by the capacity of a priori information.

The minimization of a common functional, which is a mean hazard of error classification type, is the basis to obtain classification algorithms of situations at a differing, a priori and continuous information /the algorithms with and without stimulation/.

It is shown that for some individual error function types the learning and selflearning algorithm may.be obtained either as known to the present time or as new ones.

The algorithms are applied for the construction of learning control system and a learning pulse reciver.

The experimental research results of the selflearning receiver are brought.

DETERMINATION OF THE OPTIMAL MEASUREMENT SEQUENCE FOR A NOISY PATTERN RECOGNITION SYSTEM VIA THE DISCRETE MAXIMUM PRINCIPLE

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The discrete Pontryagin Maximum Principle is applied to the problem of finding the best sequence of measurements in a pattern recognition system containing noise. The best sequence is defined as the one which minimizes a performance functional composed of the actual costs incurred in taking the measurements, the penalties that result when an incorrect decision is made as to the pattern class of the unknown pattern, and a measure of the progress toward reaching the decision.

The approach places the pattern recognition problem in the format of a stochastic finite state system where each of the states corresponds to a set of quantized probabilities that the unknown pattern is in each of the possible pattern classes. State transitions are assumed to occur at discrete instances of time and the corresponding transition equation is expressed as a four dimensional tensor equation developed from Bayes Theorem. The discrete Maximum Principle is shown to be applicable to this problem after certain requirements are established concerning the changing region from which the control variable, i.e., the kind of measurement, can be chosen. This changing region is found to vary as a function of the kinds of measurements previously used.

Compared to an exhaustive search technique the use of the Maximum Principle is shown to greatly reduce the number of basic calculations necessary to find the best sequence of gathering information.

ON CONVERGENCE OF RANDOM PROCESSES APPEARING IN CONSTRUCTION OF RECURRENT TRAINING AND ADAPTATION ALGORITHMS

by

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The paper presents a member of theorems on convergence of stochastic processes appearing in applications of the stochastic approximation method. The theorems provide facilities for evaluation of the convergence rate of the resulting stochastic processes. The well known Dvoretski, Blum and Gladyshev theorems can be obtained as corollaries from the presented theorems.

Furthermore, certain conditions for the Robbins-Monroe procedure are established, under which a requirement on square-summation of the squeezeing sequence can be weakened and replaced by a requirement of the null-convergence of the sequence's terms.

AN ALGORITHM FOR CALCULATING RECOGNITION ERRORS IN PATTERN RECOGNITION

K. Fukunaga
T.F. Krile

An algorithm is presented for calculating recognition error exactly when applying pattern vectors to an optimum Bayes' classifier. The pattern vectors are assumed to come from two classes whose populations have Gaussian statistics with unequal covariance matrices and arbitrary a priori probabilities. The quadratic discriminant function associated with a Bayes' classifier is used as a one-dimensional random variable from which the probability of error is calculated, once the distribution of the discriminant function is obtained.

A method of finding recognition error by approximating the distribution of the discriminant function is also given. This approximation, as well as the exact algorithm, is applied to an eight-dimensional example with good results.

LEAST INTERVAL PATTERN RECOGNITION AND ITS APPLICATION TO CONTROL SYSTEMS

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The work deals with some statistical pattern recognition problems with unknown form of the underlying probability distributions.
There exist many nonparametric decision rules (algorithms of recognition) which use the knowledge of a learning sequence, i.e. the sequence of the measurements with the known correct classification.
In the first part of the work some method of the comparising analysis and convergency investigations of nonparametric recognition algorithms is presented. On the basis of these considerations, the Least Interval(LI)algorithm is formulated. The presented approach consists in using the learning sequence to establish in some way the empirical distributions and then applying the Bayes procedure.The obtain procedure of the classification is the following. The recognizer computes the volumes of the multidimensional intervals in which lies the set of measured parameters in each class and then classifies the object described by these parameters into the class for which the volume of the interval is the least. It is shown that th LI algorithm is absolutely asymptotically optimal in the case in which the particular measured parameters are stochastically independent. The case of independence occurs often in the recognition of technological situations of industrial processes.
In the second part of the work the presented algorithm is applied in some conception of a learning control system with the recognition of technological situations of the controlled industrial process.

J. Barát and Gy. Muszély:

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF A STRUCTURE-ADAPTIVE PATTERN RECOGNITION ALGORITHM

S u m m a r y

A general technique is suggested for choosing n functions $\varphi_i(\underline{x})$ for the discriminant function

$$\sum_{i=1}^{n} c_i \cdot \varphi_i(\underline{x})$$

By intorducing a function $h(\varphi_i)$ for measuring of efficiency of $\varphi_i(x)$, we keep or reject $\varphi_i(\underline{x})$ depending on whether $h(\varphi_i)$ is greater or smaller than a fixed level.

The value of $h(\varphi_i)$ is determined merely on the basis of learning sample set.

Theoretical and experimental investigations were performed to conclude the advantages of the suggested method.

OPTIMIZATION OF THE PNEUMATIC INTEGRATED CIRCUITS, WITH JET DEVIATION, FOR AUTOMATIC COMPUTERS AND CONTROL

by

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R.Laurent, M.Callers

from

F.P.Ms - C.R.I.F. - S.A.B.C.A.

The realization of automatic integrated circuits through the automation of a process, beginning from models of logical components with jet deviation poses the problem of optimization of cost and of behaviour of these circuits.

This problem can be resolved by means of electric homologies utilizing R - C circuits, operational amplifiers and, in case of Coanda effect components, Schmitt flip-flops.
The present study shows how to choose the electric values of the parameters of the circuits to obtain a dynamic behaviour analogous to that of the equivalent pneumatic circuit. The inverse flow permits to fix the parameters of a pneumatic circuit homologous to that of an electronic circuit and to predict its behaviour.

The aim is to create and study homologous electronic circuits, so as to optimize the choice, the relative position and the mode of interconnection of various fluid components of the future integrated pneumatic circuit.

ON THE THEORY OF PROPORTIONAL FLOW AMPLIFIERS

Milan BALDA

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Efforts for analytical Expressing of proportional fluid amplifiers characteristics are summarised in this paper. A methode has been therefore invented which respect fundamental physical effects in the amplifier, and which enable us to calculate with agreeable accuracy all characteristics needed for circuit design, of course, if we know characteristic properties of the amplifier e.g. pressure and flow recovery and geometric dimensions. Example of an amplifier is given as well as results of experiments done on it.

DEVELOPMENT OF A FLUIDIC OPTIMIZER

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This paper describes the development of a digital fluidic optimizing controller, operating on a peak-holding principle, to be used for controlling single input extremum processes. The controller receives a fluidic pulse-frequency-modulated feedback signal, which is a measure of the extremum variable, computes an approximate derivative using a pulse-counting technique, and produces a ramp control signal which drives the process toward its optimum.

An analysis of the hunting loss for the optimizer controlling a static extremum system made it possible to select optimizing controller parameters in an optimum fashion.

For experimental purposes, the optimizer was used to maximize the output pressure of a simple non-linear pneumatic system and test results are given for both the static case and for the case including process dynamics.

TRANSFORMING OF ELECTRIC SIGNAL INTO PNEUMATIC ONE USING FREE FLOW FLUID AMPLIFIER BASED ON THE HEAT EFFECT

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The report describes:
- principle of operation,
- basic operational schema of the transducer,
- simplified analysis of the static characteristicos of the transducer.

The transducer comprises two nozzles facing each other with a heating coil built in the gap between the nozzles. Input electric signal is led to the heating coil; first nozzle is supplied with the constant pressure air, and the pressure in the second nozzle gives the output pneumatic signal.The flow of air is laminar.Any change in the electric signal rises or decreases the air temperature which changes the value. of the output pneumatic signal.

The transducer can also be designet with the coil built into the first nozzle, where, in that case, turbulent flow has to be provided. A rise of heat supplied by the heating coil causes the flow to become laminar,due to the increased viscosity. This change of behaviour of air flow results in a quasi stepwise rise of the output pressure in the second nozzle, due to the decreased friction.

PNEUMATIC MEMBRANE LOGICAL ELEMENTS

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Summary

There is a claim made for introducing to design pneumatic logical elements the following principles: of free membranes, of feed-back force, and of elimination of pneumatic resistance. The paper presents a design based on those three pronciples, and realizing a multi-input OR-function, and a multi-input NOR-function, forming a full and "over-stiffened" system, advantageous for the sythesis of logical systems. For both kinds of function the one-, two-, three-, and four-input elements, being active elements, are shown. It is pointed out that in using the supply input of an element to introduce an additional input signal, it would give an AND-function effect. It is shown how the presented design allows to use plastic materials to make parts of those elements. It is discussed how this design makes possible the automatic assembling of an element.

The main technical data are given. The laboratory tests of the following static properties of those elements are presented, and namely a switching zone, two tightening zones, and two zones of tolerance of signals.

The dynamic properties of those elements, in the form of step function response, calculated from laboratory measurements, are given.

CONJUGATE GRADIENT OPTIMIZATION APPLIED
TO A COPPER CONVERTER MODEL

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The exothermic copper conversion reactions release heat energy which can be used to melt fluxing materials required in the reverberatory furnace. Oxygen enrichment of the air supplied to the converter results in shorter processing times and increased ability to smelt flux but with increased air supply costs.

A conjugate gradient method in function space is employed to determine the optimal rate of flux addition to a calibrated mathematical model of the converter for various levels of enriched oxygen. The smelting of flotation concentrates in the converter and the effect of converter parameter variations in the optimal solutions are also considered. The mathematical model is derived from material and heat balance relationships and is calibrated using data from an operating converter.

The paper also shows how the method of conjugate gradients in function space can be applied to a bounded control problem, in particular, one in which intervals of singular optimal control arise. The conjugate gradient method is found to converge substantially faster to a better optimum than a conventional steepest ascent procedure.

OPTIMIZATION STUDIES OF A SLAB REHEATING FURNACE

by

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Control studies of large systems may often be meaningfully formulated as dynamic optimization problems. The utility of this formulation in the past, however, has often been sharply restricted by the computational difficulty associated with the solution of such problems. Promising new computational techniques for solving dynamic optimization problems are now available. This paper describes the use of one such technique in a control study of a continuous furnace which reheats steel slabs for a hot rolling mill. Among the goals of the study are closer control of final slab temperatures and minimization of fuel consumption.

A lumped parameter model of the reheat furnace is developed. When combined with an ordinary differential equation describing the heat transfer process for an individual slab, this permits the formulation of the control problem for the system as a lumped parameter dynamic optimization problem. The formulation includes as a constraint a limitation on the slab surface temperature.

A computational technique based upon the second variation is used to solve the dynamic optimization problem. The solution to the steady-state optimum control problem is also obtained.

The paper concludes with a discussion of the problem of control system design for the reheat furnace. A feed-forward controller is proposed based on solutions obtained for the steady-state and dynamic optimization problems. Results of simulating this controller are shown.

G.P. Pallard, R.W.H. Sargent

OFF LINE COMPUTATION OF OPTIMUM CONTROLS FOR A PLATE DISTILLATION COLUMN

The work reported was undertaken with a view to developing efficient numerical techniques for the study of optimum time-varying operation of non-linear systems. The particular system used as an example was a plate distillation column separating a binary mixture, and to reduce computation effort a very simple model was used, neglecting thermal and hydrodynamic effects. Two problems concerning start-up of the column were studied in detail, requiring the attainment of a specified operating state from a given initial state either in minimum time or for minimum cost. The related problem of optimum operation over a fixed period is also considered.

The minimum start-up time was determined by minimizing the terminal error for several fixed times; the minimum time is then the smallest time for which the corresponding minimum error is within the specified accuracy. The minimum cost policy involved minimizing a cost integral taken over the operating period, with or without a constraint on the terminal state. This constraint was dealt with by use of a penalty function.

After initial unsuccessful attempts to solve the two-point boundary value problem arising from Pontryagin's maximum principle, the approach adopted was the systematic improvement of an arbitrary control policy by gradient methods, using the adjoint equations to generate the required derivatives. A version of the steepest descent method applied to the control values gave a good first approximation to the optimum policy but the rate of convergence became very slow. Second order methods could not be applied to the control values because a large number of small time intervals had to be used to obtain satisfactory accuracy. However switching policies with a small number of switches usually gave a significant improvement over the steepest descent result, and they were successfully determined by applying Fletcher and Powell's conjugate gradient method to the switching times. Unfortunately the methods cannot be made automatic and require considerable judgement on the part of the user.

CONTROL BY APPRENTICESHIP
OF A PILOT UNIT OF DISTILLATION

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The problem to be resolved is that of a quasi-optimum dynamic control of a distillation column, the chosen criterion representing the gain realised at a time interval $/t_o , t_f/$:

$$J = \int_{t_o}^{t_f} I \, dt.$$

I is the gain per time unit, function in particular of the titre of the output product. I is supposed to be measurable.

When the disturbances or set values / vector $\underline{P}$ /t//, act on the system, vary, an optimum value $\underline{X}^{x}$ /t/ should be given to the vector of actions $\underline{X}$ /t/, with account being taken of pressures on these actions.

We propose a method of obtaining by apprenticeship of the law $\underline{X}_D^{x}$/t/ approaching the optimum theoretical laws, a method that does not suppose any knowledge or measure of the state variables of the system and applicable when the disturbances can be decomposed in steps as between each level variation, the column attains a permanent duty / an extension in case of disturbances that can be decomposed in ramps is also proposed/. The optimum control laws $\underline{X}^{x}$/t/ are supposed to be continuous and can be approached by an exponential sum.

The results of a study on digital computer applying a mathematical model of the pilot distillation column of the LABORATOIRE d'AUTOMATIQUE from GRENOBLE are given and experimental results, obtained on the pilot unit itself, will be provided at the congress.

A NONLINEAR DIGITAL SIMULATION METHOD APPLIED TO GAS TURBINE DYNAMICS

The problem of simulating a dynamic system, having one or more multivariable nonlinear components, on a digital computer is examined.

Such a system may be represented by a set of first order differential equations, some coefficients of which are variable.

The numerical values of the variable coefficients may be found from a knowledge of the state vector values, and the natural laws governing the behaviour of the system.

It may be shown, from a consideration of causality, that for systems as described above, an interative technique must be developed in order to solve for the system state vector.

Let there be expressions of the form, $\phi_i(y_1 \cdots y_m) = 0$

where the $\phi_{(1,\dots n)}$ represent the nonlinear components,

and $y_{(1,\dots m)}$ is the state vector.

The condition that all the ϕ_i functions are reduced to zero defines the system operating point. This operating point may be found using a technique such as the Newton-Raphson method.

In practice, each of the ϕ_i expressions is an algebraic function of the state vector, and is derived by applying multivariable curvilinear regression analysis to practical observations of the component in question.

The dynamic response of the system is determined by direct time integration of the differential equation set, following the solution for the system operating point. The time interval for this purpose is chosen so that the equation coefficients remain unchanged during the period, to a required degree of accuracy.

A general set of rules may be written down for the application of the method to any system satisfying certain criteria, the method being most suitable for systems having fairly low dynamical order, highly nonlinear multivariable components, and operating over a very wide range.

Application of the method is shown, using as an example a single shaft gas turbine engine. Results are given showing the relative behaviour of real and simulated engines.

The method may easily be adapted to include more system variables, or to give a more complex representation of certain components, until a compromise between overall accuracy and simulation complexity is reached.

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AUTOMATIC CONTROL SYSTEM, OPTIMALIZING THE BORE - HOLE BORING

G.S. Tchernorutsky, V.A. Tsygankov

Abstract

Main task in automatic control of drilling - in conditions when drilling goes in rocks with random changing of their physico-mechanical properties - to find such cooperation of structure parameters (axial tension at the head and rotation speed of drilling instrument), at which optimal structure is obtained, with exclusions of subiective factors such as operator's actions, cost of the drilling is decreased, productivity increase, conditions of work becaming better.

Comparative analysis of different techno-economical control criteriors of drilling process, permits for choosing as a criteriors minimum cost of a drilling lenght unit, which wholly considers technical and economical sides of the process.

Main disturbance, which spoils extreem cost of the drilling being random change of drilled rock physico-mechanical properties. The simpliest structure of SAU is obtained if opened self-aligning system is constructed.with nonlinear compensating connections, which uses a priori information about process. In SAU work all the time physico-mechanical properties of the area considered in which functions optimal cooperation of structure parameters are defined, which give the smallest cost of drilling. As it is seen from analysis, dynamic properties of SAU are defined by physico-mechanical properties of drilled rock and obviously absolutely casual.

For instance, some coefficients, characteristic for SAU, are changing 40 to 160 times. Dynamic properties of such a system can not be investigated by ordinary methods of automatic control.

To analyse dynamic properties of similar class SAU, it is necessary to use special approach which permits for sta-

tistical characteristic of dynamic properties of SAU. Specially, such dynamic system exponents, as stability, stability reserves etc defined by their probability. This paper shows industrial drilling tests materials, which were worked by SAU. This system is internationally patented.

On-Line Estimation of Dynamic Model Parameters from Input-Output Data.

Peterka V. , Šmuk K.

The paper deals with the parameter estimation in the difference equation of a linear dynamic system. Available for this estimation is the final sequence of the measured values of output and input signals of the system. The assumption is made that noise $\varepsilon(t)$ not correlated with the input signal is superimposed on the output signal. The mean value of noise may be dependent on time but it is assumed that the drift within the observation interval can be expressed by polynomial $E\,\varepsilon(t) = \sum_{i=0}^{\nu} c_i t^i$ where c_i represents unknown coefficients and ν is sufficiently small. Further statistical characteristics of the noise need not be known.

The method uses the algorithm of linear regressive analysis with growing data. This algorithm is described in section 3 (of the ALGOL-60 procedure inclusive) and can be also used for other purposes. It has the advantage of the on-line processing of input data and of the required memory capacity being independent of the amount of data processed. The algorithm preserves all the necessary information on the history of the investigated process in a condensed form so that passed data need not be stored.

The method proper of the parameter estimation in the difference equation of the dynamic model is given in section 4. The method exhibits the following features:

a) it can be on-line operated and the required memory capacity is not influenced by the length of the observation interval;

b) the sought for estimates are obtained by a finite number of numerical operations. In difference from other known methods iterations are not used so that difficulties with convergence and local extremes are avoided;

c) at each time (beginning with a certain minimum length of observation) it is possible to obtain estimates which in given sense are optimal for the whole past history of observation.

Section 5 contains the asymptotic properties of the estimates. With an increasing length of the observation interval the parameter estimates obtained converge towards accurate values almost with a certainty.

Results of experiments are given in section 6.

ON INPUT SIGNAL SYNTHESIS IN PARAMETERS IDENTIFICATION

M. Aoki
M.R. Staley

This paper treats the problem of designing a sequence of input signals to reduce a measure of the parameter estimation error in the off-line system identification problem. The system dynamics is given by the k^{th} order difference equation of the scalar input-scalar output variables with known input and noisy output observations.

The unknown parameters are treated as constants rather than random variables in the main body of the paper. The input is chosen to maximize the trace of the Fisher information matrix, subject to energy constraints on the input or output of the system. Closed form analytic solutions are given for the simple one parameter problem. A useful approximation procedure is developed using the Toeplitz matrix. Extension to the case where the parameters are considered to be random variables with a known joint probability distribution function is indicated at the end of the paper.

ON-LINE ESTIMATION OF THE PROCESS PARAMETERS AND ITS APPLICATION TO AN ADAPTIVE CONTROL SYSTEM

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This paper describes a method for estimating the process parameters by on-line data processing. The impulse response coefficients (parameters) of unknown process are estimated by using the method of weighted least-squares.

First, general principle and algorithm of on-line estimation are explained. Then, the statistical natures of the estimates are discussed and a concept of equivalent data length is introduced. Some existing processes have not self-regulatory characteristics. An extension of the estimation procedure for such processes is shown. In addition, the estimation of slowly time varying process is demonstrated by using computer simulation techniques. Finally an example of adaptive control system is presented.

ADAPTIVE ALGORITHMS FOR IDENTIFICATION PROBLEM

by

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This paper considers the problem of identification of systems characterized by certain parameters. Iterative method for estimating these parameters on the basis of noise-corrupted input-output data is presented.

The problem of identifying parameters of a single-input single-output discrete system is reduced to solving a set of regression equations. The estimates of certain correlation functions appearing as coefficients in these equations are constructed from the input-output data and their convergence with probability one is established using results of time series analysis. An algorithm is presented which approximates the solution of the regression equation and converges with probability one.

The approach taken for the linear case is extended to nonlinear systems. The Hammerstein model representation is considered whereby regression equations satisfied by the system parameters are found.

Examples of linear and nonlinear systems, are considered and in each case the convergence is obtained in a reasonable number of iterations.

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A COMPARISON OF SOME PROCESS PARAMETER ESTIMATING SCHEMES

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Summary

In this paper some principal problems in the field of process parameter estimation are discussed, especially with respect to the uncertainty in the estimation, caused by additive noise and approximated model structures. Two basic approaches, i.e. the instrumentation of explicit mathematical relations and the model matching technique, are compared theoretically with respect to the accuracy as a function of the observation interval.
In some situations both methods, each requiring matrix inversion, can sufficiently be approximated by the use of a non-orthogonal estimating scheme without matrix inversion.
A summarizing discussion is given on additional errors due to the approximation of the ideal estimating procedure.

Contents

AN INSTRUMENTAL VARIABLE METHOD FOR REAL-TIME IDENTIFICATION OF A NOISY PROCESS

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The problem of real-time process parameter estimation from normal operating data has received considerable attention in recent years. The various techniques developed range from largely deterministic procedures to sophisticated statistical methods based on the results of optimal estimation theory. The Instrumental Variable (I.V.) technique outlined in this paper is intended as a compromise between these two extremes; it has a basis in classical statistical estimation theory, but does not require *a priori* information on the signal and noise statistics.

The paper describes the I.V. approach to the problem and outlines the development of the simple digital recursive estimation algorithm. It also discusses how the choice of input signal and the form of the mathematical model can affect the *identifiability* of a process. Finally, a number of representative experimental results are included to demonstrate the practical feasibility of this particular approach to process identification.

MODELING AND IDENTIFICATION OF AQUIFER SYSTEMS OF HIGH DIMENSION

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The pressure distribution in an underground reservoir is modeled by a linear partial differential equation of parabolic type with space-varying coefficients. The distributed parameters, storage and transmissibility, are identified by minimizing a norm dependent upon observed and model derived pressures. These distributed parameters are approximated by "average" values over discrete portions of the reservoir. Thus, the number of parameters to be identified may be quite large.

In this paper, two different models for an underground reservoir are developed. An identification scheme based on decomposition techniques is derived to identify the unknown parameters. An important feature of the identification procedure is that it identifies automatically the areas of the reservoir having similar "average" properties. In this way a partitioning of the reservoir spatial region is accomplished along with the parameter identification. The method is based on concepts of decomposition and multilevel optimization and is specifically designed to accommodate the high dimensional systems involved.

The theoretical development of the identification scheme is given for each of the system models considered. A computational example is included and the effect of "modeling" on the results is illustrated. In addition, the computational algorithm is examined and numerical results are given.

THE APPLICATION OF REGULAR EXPRESSIONS TO THE SYNTHESIS OF COMPLEX ASYNCHRONOUS SEQUENTIAL MACHINES

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Particular problems have arisen in industry in an attempt to realize asynchronous sequential machines having several hundred binary inputs and outputs. Furthermore, these are now frequently being built using highly complex integrated logic circuits. As a result of these complications the synthesis and the repair of these units has become more and more difficult ; the classical methods of synthesis such as Huffmann's, for example, are much harder to apply, where as the detection of a faulty component causing break-down becomes almost impossible.

This paper deals with a method of synthesis based on regular expressions which tries to overcome these two difficulties : first, the authors point out how in order to obtain a more simplified table, they have been lead to modify Gloushkov's method ; secondly, they show how a parallel decomposition of machines can eventually be detecded. Finally, their method is demonstrated on a simple industrial example.

Method for state reduction of automata with taking into account the technical particularities of synchronous and asynchronous operational modes

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In the fields of control and computation different kinds of synchronous and asynchronous automata are used. For minimizing the number of states of asynchronous automata the methods especially developed for synchronous automata are not suited.

Therefore in this contribution the different synchronous and asynchronous automata are considered from a unified point of view. Their technical particularities are taken into account in the mathematical description. As to the state minimization these particularities of the individual kinds of automata appear in different conditions, under which two of their states are incompatible respectively.

According to these conditions algorithms are formulated, by means of which it is possible to find out from special transition tables all the pairs of unconditionally and conditionally incompatible states for any kind of automata.

More over a method is developed which allows to determine systematically all minimal collections of compatibility classes for any kind of automata.

By interpreting the conditions for incompatibility it is furthermore possible to compare the different kinds of synchronous and asynchronous automata in a general form with regard to the minimal number of states necessary for solving a given problem.

AN ASYNCHRONOUS FINITE AUTOMATA MODEL
/abstracts/

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An asynchronous model of the finite automaton using logical elements, each of which has its internal delay,and filters, involved into closed feedback circuits, is considered. The logical element internal delay and filter delay are random time functions with any given maximum and minimum limitations. The above mentioned model represents well the characteristics of real devices, operating as finite automata. Its particular case is a wide-known model with the non-inertial converter and delays in feedback circuits.

On the basis of the model considered the procedure for defining all the non-redundant systems of equations is given. These systems of equations provide the construction of the finite automata structural circuit free of critical races of any type. This ensures high-speed operation of the finite automaton. If optimum criterion is known it allows us to find optimum systems in the obtained set of systems. This problem is solved as easily as possible when it is necessary to minimize the number of internal states /memory capacity/ of the finite automaton.

Wiesław TRACZYK /Poland/

FULL MINIMIZATION OF STATES FOR ASYNCHRONOUS SWITCHING CIRCUITS

The paper presents relatively easy methods of internal states minimization for asynchronous switching circuits /sequential machines/. The machines are divide on two groups: statical and dynamical. In the first group the sets of pseudoequivalent states are applied for minimization and their usefulness is determines by the special theorem. In consequence we can get the minimal tables which describe the machines with level signals.

The dynamical machines are considered as the next stage of simplification. Reduction of number of internal states is obtained by appointment of the joint states and introduction of the dynamical dependences, which are realize by pulse signals.

Application of described methods gives quite new circuits, which are simpler /in majority of cases/ than at traditional methods of synthesis.

HEURISTIC APPROACHES TO RELAY STRUCTURES SYNTHESIS

M.A. Gavrilov

NOTE

Peculiarities of nowdays relay apliances synthesis tasks, such as: complications in structural conditions of elements and considerable increase of relay apliances "volume", require revision of existing synthisis methods and considerable development of relay apliances theory.

At the moment the most developed and theoretically based are synthesis methods, which give relay apliances structure realization on the elements:

" AND ", " IF ", " NO ".

Methods of obtaining, so called "absolutely minimal" realizations, are based on choosing and even for apropriate number of changables in single output structure of 10-12 order, it is practically impossible to obtain even on UWM.

And at the same time, in nowdays practical tasks, number of inpunts and outputs is counted in hundreds.

In this paper, methods of "directed" optimal realizations seeking is discussed.

Those methods conclude, that on each synthesis stage, from all possible further stages, with the help of corresponding judgments one possibility is choosen, which assures near to optimal structure realization.

At the same time from the maze of solutions, only one path is choosen, what considerably decreases quantity of calculations.

In this paper, two methods of directed chosing, which

were worked out by the author together with W. Kopylenko M.Sc. eng.are described.

First method is good for elements with symetric and order inputs and so "called" characteristic number = 1 ".

In this method, directed choosing is obtained by throwing away unimportant changables / criterion of nearness to realization by one letter/ and at putting aside of necessary subplurality of unsatisfactory minimal members / asymptotic criterion for judging of undefined functions/.

The Second method is good for any elements. Directed choosing is obtained here by choosing of optimal ~~xxiax~~ train of inputs filling /criterion of minimum,so called "hard order"/ and at optimal changables fed to inputs choosing.

AN APPROPOACH TO AUTOMATION OF THE FINITE AUTOMATA SYNTHESIS

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An appropoach to an automation of the finite automata optimal synthesis including a class of algorithms based on a structure language being algebraic equivalent of the known languages of the jump and output and graph tables of G.H.Mealy and E.F. Moore is discussed in this study. The proposed algorithm have an analytical nature. They allow conducting a single optimization line in the process of the synthesis. They are applicable to a quite wide class of finite automata and their efficiency is comparable with or exceeds the efficiency of the known analog algorithms.

The proposed approach is characterized by a high degree of formalization, convenience for engineer calculations and automation through the help of electronic computers.

HOMOMORPHISMS AND CODES FOR SEQUENTIAL MACHINES

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In this paper, we deal with a n-ary logic algebra for searching homomorphisms and for coding sequential machines.

We associate to the set of two rows of a flow-table a binary variable of which the value is 1 if we admit the possibility of merging these rows and 0 otherwise. The aggregation of these elementary variables forms a n-ary logic variable of which each value represents some degree of freedom allowed when reducing the machine. We define, in a similar way, a parting variable which can represent the constraints corresponding to the suggested mergings. From these two variables, we associate to any sequential machine a n-ary truth function which can be handled through the usual algorithms of switching theory.

It is possible in a very simple way to find from the flow-table the primitive set of implicants for this truth function, then the prime implicants. Some of these terms lead to homomorphic images of the flow-table. An algorithm leading directly to these implicants is given.

The n-ary variables can be used for searching assignments. The next value of a coding variable depends on the input and on the present state of the machine. A coding variable is determinable from a given set of coding variables if and only if we can infer its next value from the variables of the set and the input. We can compute the irredundant ways for determining any variable and represent this information by determination-graphs which give rough ideas of the assignment complexity without computing the coding equations. This method points out some particularities of structure : reductions, symmetries, equivalences, clocks, ...

The number of coding variables can be cut down : the variables likely to be the most efficient, give mergings for which the corresponding partitions are not null. By studying determination-graphs we can choose very simple assignments.

RECOGNITION OF TOTAL OR PARTIAL SYMMETRY IN A COMPLETELY OR INCOMPLETELY SPECIFIED SWITCHING FUNCTION

by

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The paper describes a method for recognizing total or partial symmetry with respect to the literals (unprimed or primed variables) in a (single or multiple output) switching function which may be completely or incompletely specified. The method represents a new approach which is based on the certain two-dimensional topological model of a switching function, the so-called function image T(f). The use of this model allows the method to be easily applied in hand for ($n \leqslant 6$-8) as well as computer calculations.

TWO COORDINATION PRINCIPLES AND THEIR APPLICATION IN LARGE SCALE SYSTEMS CONTROL

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Two principles of coordination are formulated in order to provide guidance in selecting a structure for multi-level (hierarchical) control systems. One principle is based on interaction prediction and the other on interaction balance. Both are given within the general systems theoretic framework to emphasize their wide range of applicability. Sufficient conditions for the successful application of the principles are given for two-level systems defined on normed linear spaces. Some examples of two-level systems are given to illustrate the required conditions.

DECENTRALIZED OPTIMALIZATION
OF LARGE-SCALE, DYNAMIC SYSTEMS

by

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The paper deals with the decentralized optimalization of large-scale, dynamic systems, such as: integrated electric-power system, utility gas system, water-distribution system etc.

A method based on the decentralization, or decomposition, of the optimalized system into the form of two-level control structure has been investigated. The local (I-level) controllers perform dynamic optimalization of simple sub-systems. They transmit the results of local optimalizations to the supervisory (II-level) controller, which derives, by a gradient technique, new values of constraint levels. These values are being sent back to the local controllers. As a result an iterational optimalization procedure follows.

Several extenssions of that method have been discussed.

An application of the proposed method for the optimalization of an integrated power system, including thermal and hydro-stations, has been also described and analysed.

DECENTRALIZATION PRINCIPLE AT OPTIMALIZATION OF COMPLEX SYSTEMS

A.A. Pervozvansky

Discussed is question of building of an optimal plan for the system, which consists of necessary number of elements with optinal but fixed structure of connections between them. Each element represents production of some totality of products, placed on the discharge of the system as well as on the other elements which use them as reserves.

Utilization intesity of possible system of production element means is limited with quantity of given reserves as well as with own limitations.

Decentralization principle of planning is understood as follows: system optimalization as a whole must be divided into several extreeme tasks for each of the system elements, independent in a way, that their mutual agreement does not need straight information about own reserve limitations. Several means of division procedures of combining of local functions, are described.

Main attention is paid to best known simple structures with parallel and series connections. Some receipts can be transfered on systems with general view of connections. Principal receipt being transformation of outgoing g question into totality of linear programing. with free parameters question, for choosing of which there is necessity of solution of "Central" task of secretly given convex function finding.

The last is found with the help of different modifications of possible directions method, which consider the fact of unpossibility of convex target function defferentiation at some points. Connections between task of decentralization of planning and control is discussed.

ON THE SYNTHESIS OF MULTI LEVEL LARGE SCALE CONTROL SYSTEMS

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The dimensionality of modern control problems has been increasing very rapidly in the recent years, and multi-level control systems play an ever increasing role in the control theory as well as in the applications. The synthesis of the multi-level control systems differs essentially from that of the conventional control system, and the conventional control theory machinery cannot be used. In the present paper one approach to the synthesis of multi-level control systems is presented. Using the complexity function model of the multi-level systems, a minimisation procedure for finding the admissible and the most desirable control structures is proposed.

ON A COMPLEX SYSTEMS CONTROL THEORY

A.I. Kukhtyenko

Characteristic points of complicated control systems and abstract models used for building of compound control systems, are discussed. For this, inferential and inductive ways of building of general control theory are used.

Beside this, main way of overcoming mathematical difficulties connected with studying of complicated control systems are considered. Specially, some logico-dynamic questions are solved. Some problems of a complicated symbiosis - "men-automat" in complicated controlling systems, are shown.

Some examples of complicated control systems are shown.

CONSTRUCTION OF CHECKING AND DIAGNOSTIC PROCEDURES FOR VERSALITE GENERALE-PURPOSE UNIFORM ARRAYS

I.V. Pranghishvily,
V.V. Ignatushenko

Uniform versatile arrays that may be specified to perform any desired function seem to be most promising vehicle for IC digital computers and controls systems, especially LSI-based. Checking and diagnostic procedures for uniform arrays are drastically simplified (irrespective of the function specified) as compared with those for conventional non-uniform circuits, since for identical functional cells interconnected into a regular array only checking and diagnosis are required.

A possible approach to construction of such tests is discussed and two techniques are investigated. The relevant test sets(compatible,conjugate) are found which may be applied simultaneously to all cells of an array or a certain part of it whatever the array size is.Checking time of a uniform array with these test sets(i.e. the number of operating cycles) is nearly or completely independent of array cell number(size). Checking of majority array capable of performing an arbitrary switching function is shown to be completed in 5 operating cycles for any array size; failure diagnosis needs one extra cycle per failure.A uniform array capable of performing an arbitrary sequential function is checked in 27 cycles for any array size.

ON DESIGN OF TESTS FOR DIGITAL DEVICES WITH DELAYS

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U S S R

A modular technique of unitary test is suggested for digital devices with delays. The nature of the model suggested which is a cross between combinational units and units with flipflops makes it possible to construct tests for combinational structures that would incorporate the specific features of sequential structures.

The construction algorithm uses the local characteristics of separate elements and consists of eight parts. The salient features of the algorithm are: construction of a primary tests table, construction of the sensitive path, detection and analysis of parallel paths, "expansion" of sensitive path. The resulting test detects changes in the logical and temporal characteristics of one element when the outputs of the entire structure are checked. An example illustrates the description of the algorithm.

THE THEORY OF QUESTIONAIRES AND PROBLEMS OF TECHNOLOGICAL DIAGNOSTIC

P.P. Parkhomenko

There are, of course, many E from N elements /events/; to each event Yi a positive number W/Yi/ is attached, which is defined as event weight. Given too are many T of many devided into classes E; elements from T are defined as questions; to each question tj the positive number c/tj/ is attached which is defined as question price.

To give one question - means to realise corresponding division of many E. Features, which help to define class of event at division, are defined as answers to given question.

Number of answers a /tj/ to question tj is defined as its base. Task of question giving is being recognition of events Yi EE, i.e. obtaining division of E into N single element classes.

Question cooperation from T and succesion, in which those question are given for identification of N events of many E, is defined as interrogation.

The main object in interrogation theory is to solve following questions: to construct a interrogation nark, which will have minimal overage defining price of one event.

In this paper, the features of optimal interrogators of general apperance at nonuniform weights of events, prices and question bases, are studied.

Given are formulas for transformation of given interrogation into optimal.

Clasification of interrogators is made. The most simpliest are those where prices and bases are equal, and many E reprent itself full scheme of events. They were studied by Pikar. This paper deals too, with interrogators with nonuniform bases and nonuniform question prices, as well as with interrogators of general apperance, for which algorithms of optimal interrogators construction, are given.

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In the language of interrogators, tasks of technical apliances uneffieceney diagnosis codification, are formed, as well as structure synthesis of on - off installation or other.

The main attention was paid to construction of optimal conditions for diagnostic programs.

EFFECT OF MONITORING PERIODICITY ON RELIABILITY OF RESTORABLE DEVICES

A.L. Garkavi, V.B. Grabovezky, V.B. Gogolevzky

This paper deals with some methods of certainty defining of controlled constituent installations characteristics. Proposed methods are used for solving two groups of tasks.

First group is connected with perception of periodically working installations certainty characteristics /on demand/. It is assumed, that workability control of these apliances could be made by random time spaces or periodically by equal time spaces. These possibilities define probability $P\ (t,T)$ of this, that installation will work properly at any time "t" and will work faultlessly through period "T". Solution is given for stationary and not stationary cases. Obtained results permit for control system definition, which assures given control system surety coefficients, and as well allow for prooving that regular control is much more efficient than random one.

The second group, is conducted with perception of installations surety characteristics /specially, installations of information processing/, which are supposed to process defined quantity "v" of informations in time "t". At the same time it is assumed, that time, given for processing is higher than necessary minimum for this task. Time and cycle of processing is divided into stages. In the end of each stage, by this or other method, correctness of processed information results is checked.

In this conditions, following installations certainty characteristics are defined: probability $P_z\ (V\ ,\ t)$ of information processing quantity "v" in time "t" at cycle division on "z" stages; expectation value $M\ [T]$ of time "T", which was lost for information processing quantity "v" at cycle division on "z" stages; optimal quantity of stages "z_o", into which information processing cycle "v" must be divided in order to obtain minimum $M\ [T]$.

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Results, obtained when solving second group, permit for proper organization of time diagram of installation utilisation and for some control characteristics defining, which assures full certainty of installation.

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Title

A COMPARISON OF THE PERFORMANCE OF CERTAIN PERTURBATION EXTREMUM CONTROL SYSTEMS

The performances of four different extremum controllers are compared in connection with a continuous time plant which has a brownian motion disturbance, a parabolic extremum characteristic, and white measurement noise. The performance of the controllers is described by the value of a single dimensionless variable, defined so that an optimal controller must exist.

The controllers considered are a sine wave perturbation controller, a square wave perturbation controller, a square wave perturbation controller with a sample and hold unit, and an approximately optimal controller.

The performance of the first three controllers is derived as a function of perturbation frequency and it is shown that best performance is obtained with infinite perturbation frequency, when all three controllers give the same performance as the fourth, approximately optimal, controller.

The performance of the first three controllers improves asymptotically as the perturbation frequency increases, so that good performance can be obtained with a range of finite perturbation frequencies. This enables the results to be extended to practical plants with lags of limited severity, when it is shown that the first two controllers give a better performance than the controller with the sample and hold unit, although the latter has the advantage of being easier to design and requiring less knowledge of the plant.

Summary

Reliability and Availability of Electro-Mechanical Equipment Used in Automatic Control of Turbogenerators

by T.A.W. Low

The reliability and availability of some electronic and electro-mechanical equipment is discussed. It was used in an experiment on automatic control of power systems in which 31 "machine controllers" served to control turbogenerators over a period of 18 months. These controllers were designed to meet a quantitative reliability target. The predicted mean times between failures at the stages of feasibility studies (23,000 hours) and of the finalised design (5,900 hours) are compared with the value achieved (5,740 hours). The data on components used for the predictions of reliability are given.

The availability of the equipment based on its reliability and maintenance time is calculated and its relevance in calculating the economic effectiveness of the equipment is discussed.

The effects of redundancy present within the equipment are analysed mathematically. It is shown that simple modifications of circuits switching the redundant components could halve the unavailability of the machine controllers. The methods of analysis are based on extensions of standard techniques and are valid generally.

D.A. Lloyd, A.J. Dymock

A COMPARISON OF SOME METHODS OF MULTIPLEX OPERATION

When a very high reliability is required in the operation of a control system, (for example, in an auto-pilot used for automatic landing), some form of multiplex operation is often used.

The problems of multiplex operation can be divided into two main areas: the selection of a suitable output signal, and the selection of suitable criteria for eliminating faulty units or sub-channels.

The choice of the final system output from a combination of sub-channels (for example, mean, median, or the sub-channel with the next to largest-or smallest - output) should be made so as to minimize the disturbance to the output due to discrepancies which can exist without causing a sub-channel cut-out.

In order to avoid the possibility of dangerously large disturbances to the output, (to the aircraft in the case of automatic landing), it is necessary to disconnect a sub-channel of a multiplex system if a fault occurs in it. This can be done automatically by comparing nominally identical signals, derived from different sub-channels, and taking the appropriate action if they differ by more than a pre-determined amount.

Since these signals will in practice differ to a certain extent, due to manufacturing tolerances, there is a possibility of nuisance cut-outs occuring due to this cause. It is desired to design the system so that the probability of nuisance cut-outs is low, whilst the probability of cutting out the correct sub-channel when a genuine fault occurs (for example, a runaway of one signal) is high.

This paper compares some methods of multiplex operation from the points of view given above.

SLAB TRACKING AND PRODUCTION LOGGING SYSTEM FOR CONTINUOUS HOT - STRIP MILL

O.S. Kozhinsky, R.V. Lyambach, M.D. Klimovitsky,
V.V. Naumchenko, A.B. Chelustkin

One of the most important tasks in mill controlling by means of a computer /UWM/ is preparation of a watching system of the slabs and strip checking.

Because from this system all necessary informations are fed to the computer for mill controlling, slab heating control etc.

For solution of slab watching task, a program for defined time period for the factory department in prepared.

This program is fed to the computor /UWM/.

When slabs are passed on feeding roll-way they are identyfied. Basing on prepared algorithmes, watching of each slab on its way on feeding roll-way through heating ovens and separate parts of the machine up to discharge of producted strips is arranged. Algorithmes are prepared for each technological section taking into consideration connections between different sections.

UWM solves too, problem of data gathering about milled strip, what gives possibility of supplying of each strip roll with a data card. This card consists of all required informations concerning quality and quantity: i.e. alloy number, steel quality, slab and strip dimensions, strip gauge classification, width, temperature etc.

For place indentification of slab, strip or roll on the technological line of the mill, photocell pick-offs and active current relay of rolling motors are adapted, as well as signals from different mechanisms schemes.

Data about rolled strip are fed to UWM through technological detecting elements placed on the machinery.

Instead of UWM in this system model M-2000 ASWT, was used. Model which beside solving of the problem of slab watching and production checking, will be further used for controlling of different mill machinery.

To increase surety of the system, it was decided to introduce reservation of feeding and functional arrangements of the system.

Reservation of feeding arrangements was achived by placing at each control point two or three detecting elements.

Reservation of functional arrangements was achieved by introducing of a special computor, which will work parallel with M - 2000 but for watching and checking only.

Card of in and out-going data together with intermediate internal process data, was prepared.

Enclosed is diagram of the part with UWM of the system.

Automatic Plate Rolling at Oxelosunds Jarnverk

by

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The single stand reversing plate mill at Oxelosunds Jarnverk began production use of its process computer control early in 1968. The system employs a 1.6 micro second, 96000 word central processor to perform a comprehensive array of control functions, many for the first time in this application. The major objectives were improved control of finished plate gauge and width to permit reductions in provided material - evaluated by Oxelosunds Jarnverk at approximately 2 per cent per year. The paper will review briefly the systems configuration and its major functional objectives. Operating results for the first year's production use are detailed with particular emphasis on width and gauge control accuracy, production rates and system availability. Supplier and user project organizations are described along with related changes to the user's operating procedures.

COMPUTER CONTROL OF THE COILING TEMPERATURE IN HOT STRIP MILL
- CONTROL SYSTEM OF DISTRIBUTED PROCESSES BY DYNAMIC SIMULATOR -

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The computer control system described here has a remarkable feature in that it uses a dynamic simulator operating in real time to realize accurate control of distributed parameter systems with poor measurement information.

Though some examples of control by digital computer for the same purpose have already been reported, it seems that there is no system more adaptive to quick and large disturbances than the present system.

Applying this system to 6-tandem hot strip mill coiling temperature control in Wakayama Steel Plant of Sumitomo Metal Industries has resulted in a control accuracy under 20°C in 95% over the total length of strips. Skilled manual control in the past showed 1σ , 20°C accuracy and that under those running schedules the mill operation was not so difficult to control as now.

As a recent tendency, it may be pointed out that the computer control generally relies on improvement in the computing speed and processible quantity of information, and the theory of control is inclined to fine discussions of unreal objects.

For the realization of effective control, however, efforts to match the control system to the character of the process to be controlled should be emphasized.

This paper shows the effort made in the cooling control of strips which involves many kinds of problem, and is expected to make contribution as a bridge between the control theory and the computer hardware.

From a view point of analog or hybrid technique application, the new system is not a mere low cost version of digital computer control, but it may be said to mean reconstruction of system aiming at better performance by the best use of features of the analog technique.

AN ANALYSIS INTO THE DYNAMIC BEHAVIOUR OF TANDEM COLD MILLS BY A DIGITAL COMPUTER AND ITS APPLICATION (Abstract)

by T. Arimura, M. Kamata, M. Saito ,
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The recent progress in the automation of tandem cold mills necessitates the study into the dynamic behaviour of the mills. To analyse the complicated dynamic system of a five stand tandem mill a simulation program was developed by a digital computer. By using this the variations of the gauges and tensions due to the disturbances in the screw settings and the peripheral speed of the rolls, also by hot band gauge were fully investigated. It was clarified through the analyses that the changes in the screw setting of the first stand, in the peripheral speed of the roll at the first and the final stand, and in the hot band gauge influence the finished gauge. The other factors affect the finished gauge to very small extent. The results were visualized by a digital plotter, and the delicate variations of the rolling condition at each stand through the interference by inter-stand tensions were schematically shown.

The programme was applied to the analysis and the improvement of an Automatic Gauge Control system with the results of the leveling-up in the accuracy of the finished gauge. Furthermore, a new system by computer control was proposed to maintain more consistent finished gauge than by the conventional feed-back control system.

In order to increase the productivity of tandem cold mills, the development of the Gauge Alteration in Rolling system was investigated. It was verified by simulation and also by experiments that this system requires computer programmed feed forward control instead of the built-in feed back system. This control system has other fields of application in the automation of the mill and the reduction of off-gauges. The dynamic computer control is the problem which should be solved to justify the future investment in the computer control of tandem cold mills in which on-line computers play the part beyond the judgement and the manipulation of human operators.

THE OPTIMIZATION OF CUTTING PROCESS IN CASE OF UNCOMPLETE INFORMATION ABOUT PROCESS

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The paper presented some optimization method of cutting process with uncomplete information about it. The cut band lenght is variable. After division the last segment lenght must belong to a determined range or be minimal. Described cutting process take a place in rolling mills.

The way the optimization problem is discussed in the paper is quite different from the methods applicatad till this moment.

It is assumed that the band lenght is not known exactly and yielded information about it is the summ of real band lenght and some random disturbance.

They are considered two cases : 1) when probability distribution of random variable representing disturbance is known , 2) when this distributiob is assumed a priori.

The special-purpose digital structures for optimal control of cutting process are proposed.

ON A METHOD OF CORRELATION ANALYSIS FOR MULTIVARIATE SYSTEMS

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In this paper, techniques of the correlation analysis for a multivariate system when the input random vector consists of mutually correlated components or subvectors are discussed. A multidimensional linear algebraic equation having a matrix of comparably high order can be derived.

In the case of multivariate system, correlation techniques may be used as in the case of univariate systems. But there are few papers treating the case generally when the input vector of the multivariate system has mutually correlated components or subvectors.

Here the author generalizes correlation techniques for univariate systems to the case of a multivariate system, and shows that the equation to estimate impulse responses of the system should be quite analogous to the normal equation of the regression analysis. From this result, the author proposes a method to estimate the accuracy of calculated impulse response functions by applying some techniques of multivariate statistical analysis. In particular, the author points out that techniques of simultaneous confidence interval estimations on regression coefficients are useful for the estimation of impulse response functions. He also suggests the applicability of partial correlation techniques to identification problems.

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THE METHOD OF TRANSFER FUNCTION DETERMINATION OF POWER SYSTEMS

M. Koszelnik, J. Malkiewicz, S. Trybuła

Sumary

This article is treating about the statistical method of determination of amplituda-phase characteristics and the transfer function between the active power and frequency of the interconnected power systems. The demand of active power, the exchange power and frequency are treated as stochastic processes. This method enables to determine the transfer function of every system provided that the autocorrelation functions of the exchange power and frequency as well as the correlation between this processes are known. It's presumed that the demand of power processes of this systems are stochastically independent.

After determination of the transfer function it is possible to assign the correlation function of power demand too, which can't be determinated directly by measuring because the power system possesses no such, a point at which the measurement of substitute demand of power would be possible.

The accuracy of the gained results depends very much on choosing a proper method for evaluation of statistical characteristics of the considered processes. The analysis for evaluation of different aspects of this characteristics has been evoided on the account of limitation of this article and will be published in other publication.

The described method concerns not only power systems, but in a common way assemblies of linear regulation systems too, interconnected at the input. The processes at the output and the flows on connections between this systems are known but the processes at the input are unknown and it's presumed that they are stochastically independent.

STOCHASTIC ERROR THEORY

by

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In the investigation of the characteristics of stochastic processes in the communications, measuring and control engineering it is indispensable to state the basic statistic error that is inherent in the result.

The first part of the paper deals with the theory of errors of the classic integration correlator with calculations being made in the spectral and time domains. The considerations can be transferred without difficulties on the spectral analyser.

The second part gives a review of the fields of application and some new works in this domain. There follows an evaluation of the present situation in measuring stochastic with particular regard for the correlation measuring engineering.

Buchta, H.: TU Dresden, Institut für Regelungstechnik, DDR

METHOD OF ESTIMATING OF RANDOM ERRORS IN THE DETERMINATION OF CORRELATION FUNCTIONS OF RANDOM INFRA-LOW-FREQUENCY SIGNALS IN CONTROL SYSTEMS

Comprehensive calculations are necessary for evaluating the systematic and accidental errors with the determination of correlation functions. If discrete measuring methods by means of the Stieltjes or digital correlators, especially relay or polarity correlators, are applied, precise results can be achieved only at a particularly great expenditure because of the nonlinearities occurring and the various influencing factors. Moreover, the correlation functions and other properties of the random processes involved have to be known for an estimation of the errors. Thus, here are only considered the accidental errors occurring with the determination of auto-correlation functions $R_x(\tau)$ of random, stationary, ergodic, and centered processes $X^0(t)$ which can be approximated by Gaussian processes, and the power density spectrum $S_x(\omega)$ of which exists up to an angular frequency of $\omega = 0$, and a method for estimating them is proposed.

This method permits us to give easily applicable approximate relations for determining the accidental errors for correlators working continuously or discontinuously analogously and discretely for the time delays $\tau = 0$ and $\tau \rightarrow \infty$, or $\tau > \tau_K$, respectively.

In order to characterize the spectral properties of the signals to be analyzed $x(t)$, the relations contain the effective noise bandwidth ω_0, which is approximately determined for certain classes of spectra from the zero crossings $\bar{n}_0$ of $x(t)$ through the axis $x = m_x$ when m_x denotes the mean value. Based on this, also the observation time T required and the sampling interval Δt to be fixed for the individual correlator types become approximately determinable directly from experimentally obtained records of infra-low-frequency signals originating, e. g., from industrial controlled systems, while the total course of the correlation functions or power density spectra of these signals is not included in calculations.

ON THE CONTROLLABILITY OF NONLINEAR SYSTEMS

H. Tokumaru
N. Adachi

Some discussions for the controllability in nonlinear control systems are presented. The control systems treated are described by ordinary differential equations. Several concepts concerning the controllability are introduced. If every initial state of the system can be transferred to the origin in a finite time the system is said "controllable". If the time required are infinite, then the system is "quasi-controllable". If the system has the controllability property in the neighborhood of the stationary state of the system, then the system is "locally controllable". By the definitions, if the system is quasi-controllable and locally controllable, then, is controllable. Our discussions are restricted to the systems to which controls operate linearly. We call such systems the control systems with controls appearing linearly.

Under suitable conditions the quasi-controllability of the given system of such type can be reduced to that of a certain lower dimensional control system. Hence, the controllability analysis can be very simplified.

Using this result, the controllability of some special types of nonlinear systems are considered in detail. And sufficient conditions for quasi-controllability are obtained. At last section, some examples are presented. For these examples, sufficient conditions for the controllability are obtained, connecting the conditions for the quasi-controllability and the local controllability.

ANALYSIS OF RELAY SAMPLED-DATA SYSTEMS WITH A NONLINEAR PLANT

H.L. Burmeister, DRESDEN / GDR

An exact method of analysing a class of relay sampled-data systems with additional nonlinearities, occurring e.g. in the field of extremum control of plants with parabolic characteristics, is suggested. It is simpler and applicable under more general conditions than the existing methods and proves to be practicable for numerical computation.

The method applies to plants that can be represented as L_rNL_s-chains, consisting of stable linear elements L_r and L_s of any order and a parabolic static nonlinearity N. The pulse shape is arbitrary; rectangular pulses and pure delay are included as special cases.

The sampled state variables (normal coordinates) satisfy a system of nonlinear difference equations, which is linearized by a suitable nonlinear transformation of the state variables. Transient responses may then be computed by merely performing matrix multiplications and evaluating the switching condition, which in general is nonlinear. Steady-state oscillations are determined exactly, the switching condition playing the role of a condition of existence. The mean value taken over a period, e.g. the hunting loss in extremum control systems, is evaluated without computing the oscillation itself.

The method was applied to several types of extremum control systems, in particular to second- and third-order systems. The results relate to steady-state oscillations and their existence regions as well as to the boundedness or divergence of transients.

SUBHARMONIC OSCILLATIONS IN COUPLED RELAY CONTROL SYSTEMS

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The paper develops a method for predicting the existence and relative phases of subharmonic oscillations in a two-variable relay control system. The system consists of a two-input two-output cross-coupled linear system, whose inputs are driven by relays. The relays are activated by the system error signals.

The method is essentially a generalization of Tsypkin's method and makes use of results obtained previously by the authors, for the prediction of forced oscillations at fundamental frequency, for a similar class of systems.

Certain restrictions are imposed upon the problem as follows. The two input variables, which need not be sinusoidal, are periodic with identical frequencies and zero mean but may differ in phase and magnitude. The relays are assumed to be symmetric, to possess hysteresis but no dead band and they need not be identical. They are assumed to switch twice per subharmonic period, but not in synchronism. Because of these restrictions, only odd order subharmonics can occur. The method is applicable to any odd order subharmonic, but both parts of the system are assumed to have the same frequency of oscillation. The linear part of the system is restricted only in that the elements of its transfer matrix must contain at least two more poles than zeros.

The method is mainly graphical but lends itself to implementation on a digital computer. While in theory, systems with any number of variables could be analysed by this method, the technique becomes tedious for more than two variables.

The paper includes an example which has been studied using this method and for which the predicted conditions for a third order subharmonic oscillation have been verified, with good accuracy, by analogue simulation.

FUNDAMENTALS OF NONLINEAR CONTROL SYSTEMS WITH THE PULSE - FREQUENCY-WIDTH MODULATION

V.M. Kuntsevich, Yu.N. Chekhovoy

Discussed are nonlinear impulse automatic control networks consisting of uninterupted linear part /ULP/ and nonlinear impulse modulator of the 1-st kind /IM/.
IM modulates train of right angle control impulses to the mark, frequency and time space in dependence to linear combination of sampled meanings of network coordinates.
For defined networks we are using natural meaning of phase space E^m with coordinates Xn, $X_n^1........,X_n^{/m-1/}$ and phase space difference with coordinates $X_n, X_{n+1}.....X_{n+m-1}$.
In both phase spaces we are finding different moovement equations and there is a conection between them.
We are defining sampled analogue of J.La-Sall theory, which is a form of generalizing of A.M.Lapunow theory about asymptotic stability. Basing on La-Sall theory it is shown, that Lapunow function - quadratic form - guaranties obtainance of discussed network stability, if it is in accordance with P.W.Bromberg theory /i.e. if is defines stability of ULP/, and satisfactory conditions in all equal network conditions, are obtained. This condition have got an apperance of an analitical inequality, which depends on one limited parameter.
Sampled analogue of T.Yoshizawa theory about limitation of nonlinear impulse systems is defined. Basing on this theory, methodology of asymptotic plurality stability limits definition within which all phase trajectories of the system are ended, is proposed.

Proposed is precised methodology of limited cycles finding and their stability investigation.

Parameter defining method of stationary systems regime which follows linear time function is given.

For found out simple Lapunow method basis, stationary, regime, stability conditions in whole are obtained.

ANALYSIS OF NONLINEAR A.C. CONTROL SYSTEMS

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This paper presents a method for the analysis of a.c. carrier systems having nonlinearity in the a.c. link. Conditions are derived under which linear transfer functions in the a.c. link may be transformed and shifted to points in the low frequency portion of the system. The remaining modulation-nonlinearity-demodulation process is shown to be equivalent to a modified nonlinearity. Properties of symmetry and single-valuedness of this nonlinearity are derived and their effect on system behaviour is illustrated by means of examples.

A number of special modes of operation of a nonlinear a.c. feedback system, which are not predicted by a simple describing function analysis, are discussed and illustrated by means of tests on a small a.c. position control servomechanism.

ON OPTIMAL RESOURSE ALLOCATION

by A.J. Lerner and A.I.Teiman

This paper presents the basic principles for the formulation of the resourse allocation problem. Solution of the problem yields the best possible value of the objective function which is a measure of both the result and the technique used to achieve it.

The controlled plant is a set of related activities described by a network or matrix model.

Of special importance for practical applications are the cases when the functional Φ defining the objective of the project incorporates the project elapsed time - T, available resources R probability of meeting P scheduled date T, qualitative parameters of the project results. Depending on the parameters included in the objective function various types of problems arise.

Types TR and TP problems are investigated in the paper. A number of deterministic optimal resourse allocation problems are presented and methods of their solution are suggested. Examples are given.

A project control problem under uncertianty is stated. A project realization model is developed and studied. Some specific problems associated with the general problem are considered.

A short review of the results obtained in this field is given and possible approaches to further research are discussed.

ON STOCK CONTROL THEORY

A.A. Voronov, S.B. Lovetski (MOSCOW)
V.A. Avdiyski

Function of a large systems can be studied as a complex of target - guided operations. One of the most important points of controlled actions when whole complex of operations is controlled, is divission of stocke between operations. But stocks in given system are not unlimited and their entering from outside can not be at any time and any quantity. In connection with this stock control is a very important component in controlling of limited resources, i.e. not used resources at the moment, but stored for faultless operation in future. In the process of operation control, two main stages can be detached; establishing of optimum action program and realisation of this program, including corrections caused by deviations during action.

In this paper the first stage of given stock control is discussed, i.e. construction of optimum plan of stock controlling for given article complex, which are coming in from factory interval stores and from outside at fully defined or random, in quantity, order.

RESOURCE ALLOCATION IN MULTI-PROJECT BASED ON AGGREGATION OF THE PROJECT NETWORKS

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A solution method for a problem of limited resource allocation among several activities in a multi-project is considered. Aggregation of complexes of the activities, i.e. replacing the complex by a one activity enables to present the solution of such problems by means of the following stages:

1. Aggregation of the each complex, described by a one network. Thus, each complex can be represented by a one activity, for which all necessary parameters are determined during the aggregation process from given parameters of the complex'es activities.

2. Solution of the problem of limited resources allocation between independent activities / complexes / with a given optimization criterion.

3. Solution of problems of resources allocation according to number of the independent activities from activities of the each complex, when considering the resources limitations determined at the previous stage.

Hence, the problem of limited resources allocation between $n = \sum_{p=1}^{l} n_p$ activities leads to the solution of l problems of resources allocation between n_p $p = 1,2,\ldots,l$ activities, where n_p is a number of activities in the p-th complex and l is a number of technologically unconnected complexes in the considered multi-project.

A general approach to aggregation problem of activity complexes as well as the aggregation process'es stages are described.

Moreover, an optimum aggregation method is considered for a case when the each activity rate linearly depends upon the number of resources provided for its execution.

OPTIMAL PROJECT CONTROL
by V.N. Burkov

(Moscow)

The resources allocation problem with one type of resources is considered. The project consists of n activities. The activity speed is the power function of the resource value.

The problem is to find resources allocation so that to provide minimal project time under limited resource level. The following properties of the optimal solution are proved.

a) under the optimal solution the resource value is constant for each activity;

b) the resource values form the flow in the project network;

c) some shortest route between two points of a region in the q-dimensional space corresponds to the optimal solution (q is the network dimension).

Let τ_i^0 be the acitivity times for the minimal resources level problem under the given project time T.

Consider minimal cost problem under the same project time T. Assume that

$$S_i(\tau_i) = \frac{W_i^{\alpha}}{\tau_i^{\alpha-1}}, \quad \alpha > 1,$$

where $S_i(\tau_i)$ is the cost-time function, W_i is the i-th activity volume. It is found that the optimal solution of the problem is τ_i^0 also.

New algorithm for the solution of the resources allocation problem is proposed which basically is the algorithm of the shortest route foundation.

SOME QUESTIONS ON THE TESTING AND CONSTRUCTION PRINCIPLES OF AN OPTIMUM MULTILEVEL CONTROL STRUCTURE IN SYSTEMS WITH A SPECIFIC OBJECTIVE FUNCTION

M.K. Babunachvili, S.S. Naumov, D.J. Golenko

Form of controlling sub-systems with some direction function, is discussed. For those systems, determination algoritm of sampling step and a formula for quantity estimation of profilactic questions such as functions from subsystems parameters, is proposed.

The system consisting of similar subsystems is described with a principle that discussed subsystems are ruled by one controlling system of a superior range.

It is being assumed, that quantity of questions, necessary for control, should decrease with increase of hierarchy range.

Shown limitation, put on the system determines necessary condition of optimalization of hierarchic structure. It is being prooved, that obtained condition is sufficient in the local meaning, too.

ELECTROMECHANICAL TRANSDUCERS, COMPARATIVE PROPERTIES, BASIC CHARACTERISTICS AND FIELDS OF APPLICATION

A.P. Shorygin

The new tasks in the field of automatic control stand new requirements as far as pickup and information converters are concerned.

Those new requirements are: decrease in levels and input actions frequency, decrease in required rating, getting of output signals directly in from of a given code without utilization of additional converters and others.

In this case arises necessity in comparison of characteristic fields of electrochemical converters parameters and converters which are based on other principles in judging utilization fields.

In this paper are discussed peculiarities and superiorities of electrochemical integral elements for bigger integration time spaces, characteristic ranges and faults for different types of integrals with analoque and sampled output, diodes for a very small currents of infralow frequences; elemenst with negative resistor; elements, analyzing operation p in wide range of a very low frequences.

Given are characteristics of hard phase canal electrochemical triodes, which are utilized as analogue memory elements with unmoovable reading in adaptive control systems in controlled filters, amplifiers and others.

There are described electrochemical non resonance detecting elements of small pressure, and pickups of small pressure gradients of infrasmall frequency, which are good for the work in high statical pressure; pickups of small angle and linear displacements, speed and accelerations.

THE SOLID ELECTROLYTE OXYGEN SENSOR
THEORY AND APPLICATIONS

S. J. Lawrence, H. S. Spacil, and D. L. Schroeder

Zirconium dioxide, when heated to above 600°C, becomes sharply less resistant to electrical flow and specifically conductive to oxygen ions. A voltage is generated according to the Nernst equation. The theory of this oxygen sensor is discussed. Practical applications in research development and production are described.

VOLTAGE-CONTROLLED MOS-FET RESISTOR

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It is shown how the normally nonlinear MOS-FET channel resistance can be linearized and thereby used for the control of ac or dc circuits without introducing distortion. Being an electrostatic device, the MOS-FET has a high input resistance (more than 10^{13} ohms) and requires only very low drive power (less than 1 μW). Examples for MOS-FET applications are: long-time timers, variable R-C time-constant circuits, voltage controlled attenuators, adaptive controls, multipliers, amplifiers and modulators.

As a practical example, a linearized MOS-FET is described as part of a phase shift circuit for the control of thyristors, etc., covering the range from power frequencies up to 200 kHz. Measured data of phase-shift angle versus gate control voltage are shown. Oscillograms of the phase shifter output voltage conclude the report.

SOLID STATE ELECTROSTATIC CONTROL ELEMENTS OPERATING ON PIEZOELECTRIC PRINCIPLES.

by F L N-NAGY, Dip. Eng., C.Eng., MIEE,
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A new generation of electrostatic high impedance control elements is now becoming available to supplement the current range of electromagnetic, low impedance devices. Their very impedance incompatibility with most present devices is proving beneficial in that they are non-interacting and thus do not suffer from unwanted electromagnetic disturbances.

The paper describes new controlled actuators for use in servo-mechanisms. Examples are flexural, torsional bimorph elements, crystal motors, e.g. two-phase/one-bridge, two-phase/two-bridge, and four-bridge rotary version motors, hydraulic and pneumatic valves, etc., all operating on the electro-static/piezo-electric principle. A flexural and torsional bar can be constructed together in one unit to form a bending-torsional bimorph which operates for a composite movement. The basic principle of operation of the actuators depends on a novel application of the converse piezo-electric effect in a crystal, i.e. it makes use of the mechanical strain produced in a cyrstal structure by a controlled electrostatic field.

An application of various piezo-electric crystal control elements will be shown in actual control systems. The first application of a crystal actuator as part of a computer store magnetic head alignment control will be illustrated in operation for reducing skew, wow and flutter irregularities between a multitrack magnetic head and one inch magnetic tape. The control has effected a reduction of 20-30 dB of the skew in the frequency range 0-100Hz. The application of crystal transducers to control systems in computer store instrumentation appears to be particularly promising since compensation for variations in tape speed, tension and alignment can be made by a servo control of the magnetic head alone. In this way a single control can replace a number of separate control operations.

The "bimorph" actuator in flexural mode will be theoretically discussed deriving its transfer functions. Developments are in progress for multi-composite constructions, that is multimorph elements, which are more suitable for servo components.

PRECISE HIGH-SPEED ABSOLUTE POSITION CONTROL USING A MULTI-TRACK OPTICAL GRATING

A. Russel

SUMMARY

A method for obtaining absolute analogue position information from multi-track optical gratings is described. Criteria for interpolation accuracies of various systems are discussed and methods for achieving them are suggested. The frictionless transducer is suitable for precise high-speed digital positioning machines.

STAGNATION TEMPERATURE PROBE WITH A SERVO-CONTROLLED RADIATION SHIELD

H.A.Trucco

Temperature measurement in high temperature gas flows by immersing a shielded thermocouple probe involves a systematic error mainly caused by the radiation loss of heat. This error is characterized by a probe recovery factor lower than unity.

After a review of the existing techniques for high temperature measurement, a new probe is described. This probe has a radiation shield, the inside surface of which is an electric heater fed and controlled by an electronic servo in such a way that the probe transient response is improved and its steady state radiation error can be minimized.

The system governing equations are discussed and analyzed by the analog computations technique to give stability and response behavior.

Solutions were obtained for a typical thermocouple used in a supersonic air flow at 2000°F average. The proposed probe exhibits no radiation error after reaching steady state conditions. The proposed system increases the response of the standard shielded thermocouple analysed by 333 times, so that in 3 milliseconds, the probe reaches 99% of the amplitude of the step input.

RATIONAL ALGORITHM OF CONTROLLING THE THERMAL CONDITION OF BLAST FURANCE USING COMPUTERS

E.L. Suhanov, V.C. Shvidkin, B.I. Kitajev, Ju.G. Jaroschenko
Ju.N. Ovchinnikov, V.G. Lisienko

The autonomy in heat operation of upper and lower stages in a blast furnace called for the necessity of different evaluation of their heat conditions. „The index i_B" is offerred as a general variable of the heat condition in the upper part of the blast furnace and „the index i_H" is proposed for controlling heat conditions in the lower part of the furnace. These variables are calculated only once per cycle of the furnace charge according to usual information about the technological process.

The blast furnace should be considered as two connected but independent objects of controlling with their own static and dynamic characteristics. When analyzing those characteristics the conclusion about real combination of such controlling factors is obtained. The general influence of these factors on the furnace heat conditions has its necessarry local action.

Both statics and dynamics of transient processes in objects of controlling are considered. Each controlling effect is a certain programme of the necessarry digital changes in the temperature and humidity of the blast, in the higher oxygen concentration and in the expense of the injected fuel. The lower specific expense of the coke can be assumed because of economic consideration. All the calculating operations are performed by the information controlling machines. In the article the possibility of stabilization and optimum heat conditions in the modern blast furnace which is worked at a combined blast is proved. The bloc-diagram of the automation system which is resulted from the idea about the optimum in the blast furnace process under the independent control and the local stabilization of the heat conditions in the upper and lower stages in the furnace is given.

Anatol GOSIEWSKI, Andrzej WIERZBICKI /Poland/

DYNAMICAL OPTIMIZATION OF STEEL-MAKING PROCESS IN ELECTRIC ARC FURNACE

Report presents an idea, technical design and preliminary experimental results of the dynamicaly optimal control of the steel-making process in electric arc furnace. As a performance measure of the process the unit production cost has been assumed /the cost of electric energy and the cost of time combined/. A system of ordinary differential equations has been taken as the mathematical model of the process. The theoretical problem of process optimization has been solved by means of the maximum principle. An idea of expanding problem of the combined optimization of the arc furnaces complex with regard to the constraints is also discussed in the report.

The technical design of both open - and closed loop optimal control systems /being under construction and implementation/ is presented.

The experimental results of the optimal control of arc furnace based on prepared algorithms are presented at the end.

<u>OPTIMAL OPERATION OF BLAST FURNACE STOVES</u>

H. Kwakernaak, P. Tijssen, R.C.W. Strijbos

The investigation is concerned with the dynamic optimization of the staggered parallel system of operating blast furnace stoves. Stationary periodic operation is assumed and optimality is defined in terms of thermal efficiency. The optimization equations are formulated and a numerical approach is developed. Numerical results are given and a comparison is made with two types of four-stove serial operation. It is found that staggered parallel operation of the stoves is not very critical and that it is thermally more efficient than serial operation.

CLOSED-LOOP TIME OPTIMAL CONTROL OF A SUSPENDED LOAD - A DESIGN STUDY

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The time optimal control of a suspended load has particular practical importance in the unloading from ships, by bridge crane, of bulk cargo such as iron ore. The minimum time control strategy is a good approximation to the actual economic requirements and gives accurate positioning of the load, avoiding damage. Accounts of several open loop schemes have been published, but they do not successfully handle a wide range of initial conditions, particularly of load swing. This difficulty is overcome in the present study by using either a closed loop or updated open loop implementation.

The optimal control as a function of time is found by applying Pontriagin's Maximum Principle to a simple model of the system, with linearised dynamics and control input saturation, for a nominal set of initial conditions. A modified sensitivity analysis has been developed to obtain from this the solution for an accurate representation of the system dynamics including time varying rope length and nonlinear velocity feed-back on the traverse motion. The optimal control for various other initial conditions of interest is determined using a conventional Newton-Raphson technique.

A nonlinear algebraeic equation is produced for the control input in terms of the four state variables by a nonlinear multivariable regression analysis incorporating a learning mechanism. The same technique is used to produce an equation for the control variable switching times in terms of the initial state. Either equation may be used in a practical system, but the latter shows better performance and simpler implementation.

Results for both analogue and digital simulations are given, showing improvement in performance over a conventional scheme using linear feedback of the state variables.

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Time-suboptimal control of cranes with special taking into the consideration of practical realization

Summary

The realization of time-optimal control meets great difficulties in determining of control signal, as well as in practical realization. Application of that type of control is rarely possible and profitable.

In this report there is the relation about subotpimal control of a crane which shows a let of advantages in proportion to the optimal control. This control has been obtained on the basis of analysis of optimal control. With small loss on fastnes of acting the control signal has been greatly simplified.

The descrebed proposition of controlling has been confirmed by the results of testing obtained by means of control with a model crane.

COMPLEX AUTOMATION OF THE DEPARTMENT BLAST FURANCE - SINTERING PLANT - RAW MATERIALS DEPOSITS, OR THE INTEGRATED IRON WORKS GALATI, BY MEANS OF COMPUTER CONTROL

G. Scripcaru, C. Paius, O. Stoicovici, M. Popescu

COMPLEX AUTOMATION OF THE DEPARTMENT BLAST FURNACE - SINTERING PLANT - RAW MATERIALS DEPOSITS, OF THE INTEGRATED IRON WORKS GALATI, BY MEANS OF COMPUTER CONTROL

A process computer has been installed at the Blast Furnaces Department of the Integrated Iron Works Galati with the aim of achieving the complex automation of the ensemble Blast Furnace - Sintering Plant - Raw Materials Deposits.

For the blast furnace, the computer accomplishes data logging, the charging report, the correction of the quantities of raw materials in the charge and the optimization of the thermal process, using a mathematical model.

For the Sintering Plant, the computer accomplishes data logging and the optimization of the sintering strand.

For the Raw Materials Deposits the computer draws up the report for the transport operations and the report for the stocks of raw materials, according to the sorts and depositing points.

The actual installations is briefly described and a summary of the operating data is given as well as a summary of the computer programms used.

ON-LINE CONTROL OF VOLTAGE AND REACTIVE POWER FLOW IN ELECTRIC POWER SYSTEMS

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As electric power becomes satisfactory in its quantity, the quality of electricity has been required. "The quality of electricity" means chiefly frequency and voltage.

A lot of methods and apparatuses have been developed for automatic frequency control. Automating system voltage control / var dispatch, however, have hardly been considered.

Up to now voltage and reactive control have been done by using automatic voltage regulators of generators and synchronous condensers, tap changers under load, shunt capacitors and reactors being located at various points and operated manually or with conventional automatic apparatuses. Therefore it was quite difficult to get a co-operative control of these devices in electric power systems.

This paper deals with the apparatus (AQC) and control system to solve such difficulty and results of some field tests.

The Design Works Testing and Initial Site Testing of the Computer Based Control and Instrumentation System for A Thermal Generating Station

by J. H. Osborn M. F. Delahunty P. R. Maddock & C. Ayers.

SYNOPSIS

The paper describes the reasons for applying a computer based control and instrumentation system to each 500 MW boiler/turbine generator unit in a 2000 MW oil fired station.

The paper first appraises the facilities offered by such a system and then discusses the design and programming methods adopted for the integration of the central system with the main plant. In particular the paper describes the solutions adopted for the system interface and details the methods of the transfer of information between the Project Design Staff, the main plant contractors and the central system suppliers and their programmers.

The paper continues with a description of the Works Testing of individual modules and sub systems and then describes in detail the method of Works System test. Particular reference is made to the procedures for Program Testing including the simulation of the plant during this important test phase.

Following the initial site installation of the system the methods of commissioning the main plant using the control system and its program are described.

The paper concludes with a summary of the lessons learned on the project and which are being applied to the next project which is in an advanced state of design and manufacture.

AN APPLICATION PROGRAM FOR
THE PROGRAMMED CONTROL AND INSTRUMENTATION SYSTEM
OF A NUCLEAR REACTOR

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A digital computer has been interfaced with a nuclear reactor instrumentation and control system. The test reactor's electric heating system, rated at 384 KW, can heat it to 1000°C. Its graphite moderator is blanketed with presurized nitrogen to inhibit oxidation. The digital computer directly controls the nitrogen and heating systems, and provides operational aids for the reactor personnel.

Control techniques for four closed loops in the heating system were programmed on the computer. The basic, digital, simulation of a proportional-plus-integral controller was modified to provide several notable features: (1) aids in controller adjustment, (2) transducer signal conditioning, and (3) compensation for process nonlinearities. Other features of the control system reduce operator errors during start-up and operation of the nitrogen and heat systems. A significant feature of the design of the control programs was the extensive use of hybrid simulations.

AUTOMATIC CONTROL OF AN INDUSTRIAL PLANT - USING BY DIGITAL COMPUTERS

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SOCIA

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The paper describes the application of the complete automation of a nuclear power plant (EL.4 - Monts d'Arrée plant) handling at the same time logical and control actions.

The structure of this automatism is described and the reasons of the function distribution between computer automatism and wired automatism are explained. Furthermore is particularly described the structure of computer automatism which has several original features. The logical structure of the automatism is described which makes it necessary to give the precise definition of the states for each of the components before explaining the exact structure of the various programs carried out by the computer.

These programs have in common a great number of feature (modularity, repeatability, easy coding and modifications, brevity, language) which made their application easy. This has led to operate the Monts d'Arrée power plant since its initial start-up with the possibilities given by the automatism ; the application of this structure for conventional plants is of course possible.

AN EXPERIMENT IN THE AUTOMATIC CONTROL OF POWER GENERATION IN A LIMITED AREA OF THE C.E.G.B.

by F. Moran and J. N. Prewett

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Control of the generation of electric power in an area demands a considerable amount of on-line computation involving a forward prediction of demand and the scheduling of load among generators in the most economic way consistent with maintaining security of the supply against loss of a transmission line and satisfying the demand in the event of outage of a generator. A series of experiments has been carried out in a limited area of the C.E.G.B. system, in which a computer was used on-line to predict the demand and schedule the load among 31 generators. The generation from each set was instructed directly by the computer through a machine controller.

The experimental system is described and the results discussed. The performance of the automatic system was shown to be superior to that of conventional manual control in that operating costs and spare generation are more closely controlled although it proved impossible to demonstrate quantitatively an improvement in economy due to difficulties of measurement associated with day-to-day variations in demand and system configuration.

When operated as an isolated area, the system was shown to be stable and to be capable of much closer control of frequency. Practical difficulties were experienced in defining the operating constraints which the load schedule must satisfy and in updating these in the computer. The load schedule was subject to supervision by the Control Engineer through a cathode ray tube display and improvements are necessary in the method of communication between the operator, the computer and the display.

Analysis of Dynamic Stability of a Power System under Deterministic Load Changes

J. Preminger and G. L. Park

The dynamic response of a ten-generator electric power system is simulated on a digital computer using the COBLOC hybrid computer simulation language. Block or transfer-function models are derived for each turbogenerator, and the effects of synchronizing torque between generators is calculated from load-flow data. The dynamic response studied is that due to small load changes which do not result in configuration changes in the electrical transmission network and which do not cause transient instability. A measuring instrument to verify the simulation results is described and extensions to include slip damping and pumped-storage installations are discussed.

ADAPTIVE CONTROL OF INTERCONNECTED POWER SYSTEMS

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The principle of the control of the interchanged power of interconnected power systems is well known as the "tie-line control".

For the sake of security of the power system, it seems appropriate to take the temperature of the conductor of the tie-lines as criterion for the optimal adjustment of the interchanged power control.

In view of reducing to a minimum the control work of the regulating plants, fluctuations in the interchanged power can be accepted as long as the variations in the tie-line temperature which are limited by conductor thermal inertia, do not exceed a safe limit.

When the meanvalue of the interchanged power is small, it is possible to accept big fluctuations of this temperature ; the response of the control system can be smoothed. When the meanvalue of the interchanged power is relatively high, or in case of emergency after a perturbation, a quick response of the control system is required, to prevent an overload and an overtemperature of the tie-line.

Using the dynamic statistical analysis, this report determines the rules of an adaptive control of interconnected power systems, it means how to adapt the dynamic characteristics of the controller, according to the load of the line and in case of emergency ; different methods to determine the case of emergency are discussed.

The efficiency of such an adaptive control is demonstrated with a model using the hybrid simulation.

Mr STABILITY AND PARAMETER SYSTEMS

C. LEFEVRE - A. RAULT

This article presents a new concept of stability, which, when applied to a class of parametric systems, permits to establish a geometrical criterion. This criterion is easy in use and the results are compared to those obtained by the classic criteria. This notion of stability refers to the principle of contraction and to the physical notion of power dissipation.

AN EXTENSION OF THE HARMONIC LINEARIZATION TECHNIQUE

E.P. Popov, E.I. Khlypalo

There is a comparatively vast class of nonlinear automatic systems for which the application of harmonic linearization methods gives incorrect results. A new variance of the harmonic linearization method is decribed. Using the method, one obtains results, which may be approved by the experience of nonlinear system design and accurate computations.

The essence of the variance lies in the fact, that a form of harmonic linearization of nonlinearity in the pattern of equivalent inertial section, that contains a varying amplification coefficient and time constant, is given. When analysing transient processes, the parts depending upon the parameters of the unknow transient process are also included in the equation.

The new form of harmonic linearization responds better to the phisical meaning of the problem and gives more accurate results in the mathematical sense.

THEOREMS ON THE EXISTENCE OF PERIODIC VIBRATIONS BASED UPON THE DESCRIBING FUNCTION METHOD

by

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A nonlinear feedback system described by equation

$$x(t) = \int_0^\infty u(t-\tau)\, dh(\tau) + z(t); \quad u(t) = [Fx](t) \qquad (1)$$

is considered, where $h(t)$ is a function with bounded variation, F is the mapping of a set of T-periodic functions into itself, and $z(t)$ is a T-periodic function. The function $h(t)$ and operator F characterise the linear time-invariant part of the system and nonlinear element, respectively, and $z(t)$ represents the excitation of the system.

The describing function method is frequently used for an approximate examination of nonlinear vibrations in system (1). In the paper two theorems on the existence of a periodic solution of Eq. (1) in a given neighbourhood of approximate solution obtained by describing function method are formulated. The first one deals with nonautonomous systems having a periodic solution with the period T determined by the input $z(t)$. The second one deals with autonomous systems for which the period of the solution ought to be calculated.

In order to prove these theorems the idea of reducing Eq. (1) (with the compact mapping) to an equation in a two dimensional space is used and the topological method of rotation of the vector field is applied in order to solve the second equation. Both theorems are ilustrated by examples. In each of them the Banach space containing the solution is chosen for the given mapping F. One of the examples is referred to the system having an element with a discontinuous characteristic.

STEADY STATE ANALYSIS OF NONLINEAR SYSTEMS AND MULTIPLE INPUT DESCRIBING FUNCTIONS (M.I.D.F.)

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The describing function technique is considered as a special case of the more general problem of determining the amplitude of any frequency component in the output of a single valued nonlinearity with a multiple frequency input. By using a power series, Fourier transform, and Fourier series, respectively, to represent the nonlinear input-output characteristic, three formulas for the amplitude of any output frequency component are derived. The formula based on the Fourier series representation of the nonlinearity is presented in detail with a discussion of numerical techniques for very rapid computation of output amplitudes.

As an important special case (in automatic control theory) of the above methods, both the exact representation and an efficient numerical approximation for the Multiple Input Describing Function (M.I.D.F.) are presented.

These methods are generalized for cases when the input frequencies are harmonically related. It is shown that the formula for any output amplitude in this case is given by a Fourier series (with respect to input phase), the coefficients of which depend only on the input amplitudes. This series is shown to converge rapidly, allowing efficient numerical computation. Again the describing functions for problems with harmonically related input frequencies are special cases of this method.

As an example, a subharmonic Dual Input Describing Function (D.I.D.F.) is considered, and its relationship to the D.I.D.F. for unrelated input frequencies is established. Typical curves are given and the numerical methods used for their computation are discussed. The third subharmonic oscillation of a system is investigated by means of these curves.

ANALYSIS OF HARMONIC AND ALMOST PERIODIC OSCILLATIONS IN FORCED SELF OSCILLATING SYSTEMS

P.K. Rajagopalan
Yash Pal Singh

Summary

The paper presents a simple method of investigating the almost periodic oscillations in forced self-oscillating nonlinear systems containing one, single valued odd nonlinearity. The method assumes that the input to the nonlinearity can be represented by the fundamental components of the unsynchronized free and forced oscillations, and makes use of the dual input describing function of the nonlinear element for incommensurate frequencies in conjunction with the universal chart. The proposed method is particularly useful for studying the phenomena of synchronization and desynchronization and its application has been illustrated by studying the forced oscillations of (i) the Van der Pol oscillator and (ii) a third order relay system, over a wide range of amplitude and frequency of the forcing signal. The proposed method has the advantage that it gives a clear picture of several of the phenomena involved, is applicable to system of any order, and retains its simplicity even for higher order systems.

The possibility of applying the incremental frequency response technique for determining the stability of the almost periodic oscillations has also been examined, leading to an original concept, the incremental dual input describing function (IDIDF). Based on this, criteria for the stability of solutions obtained by the universal chart are discussed. The expressions for the IDIDF for several nonlinear elements are also included.

COMPUTATION OF INITIAL STATE REGIONS FOR SYSTEM STABILITY VIA FREQUENCY RESPONSE CRITERIA

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For a class of single-loop systems consisting of a linear time-invariant element and a nonlinear and possibly time-varying element, algorithms are presented for the computation of stability boundaries in state space. These algorithms are presented in terms of algebraic relations involving the frequency response characteristic of the linear element and certain relations involving the nonlinear element. They are also applicable for the computation of bounds on initial functions for systems containing time-lag and distributed parameters.

DESIGN AND APPLICATIONS OF MULTILAYER CONTROL

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The paper discusses some aspects of the systems design problem in the implementation of control of complex industrial systems. A hierarchial approach is presented as the basic framework for carrying out the design process following a sequential and iterative procedure.

Two aspects of the hierarchial structure are developed. In the *multilevel* control hierarchy, the complex system is decomposed into a set of simpler subsystems, each subject to control based on a local model and a local criterion. Higher level controllers serve to coordinate the actions of the local controllers so as to best serve the overall system objective. In the *multilayer* structure, the complex control problem is decomposed into simpler subproblems each of a form readily solved and implemented by existing techniques. The subproblems are integrated through higher layer control functions, again in consideration of the system objective.

The proposed structure for the control system provides a rational procedure for simplifying the control problem and for effective utilization of information feedback in updating the control or decision-making algorithms. Implicit in the design procedure are considerations of economic tradeoffs relating incremental costs versus benefits associated with the control function.

The hierarchial approach is predicated on the use of the computer for fast-time simulation, information processing and on-line control.

Many of the concepts and guidelines described are illustrated in the context of a specific system application.

MULTISTAGE OPTIMIZATION OF A PRODUCTION SYSTEM USING A DISCRETE VERSION OF PONTRYAGIN'S MAXIMUM PRINCIPLE

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In this paper, a method has been developed, using a discrete version of Pontryagin's Maximum Principle, to determine the optimal production schedule of a production process by considering its dynamic response to various decisions. The optimal strategy is a sequence of decisions that minimizes a cost function over the entire planning horizon. This cost function encompasses production-inventory cost, and the costs associated with some system parameters. Since the system parameters are costed, therefore the optimal solution not only defines the optimal sequence of decisions with respect to a particular set of parameters, but suggests if it is advisable to incur a certain cost to improve the system parameters so as to achieve better performance.

The algorithm developed in this paper requires much less storage capacity of a digital computer than a straightforward application of dynamic programming. The algorithm has been programmed for application in some manufacturing processes in the Western Electric Company.

THE OCCURRENCE AND EFFECT OF DATA LOSS IN A HIERARCHICAL DIGITAL COMPUTER SYSTEM PROVIDING ON-LINE PROCESS CONTROL

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In a fully deterministic system theoretical values of speed and size may be evaluated for each separate computing element and results in a Linear Programming problem which will yield, within limits, the most economically viable configuration.

For a system, which is subject to statistical variation the upper-bound cost must be off-set by the cumulative effect of data loss on the efficiency of control provided. Considerations which may cause perturbations from the steady state working of the system include the following: rapid change of state or control variables demanding an increase in sampling rates with consequent effects on the quantitiy of data handled and its processing time. Breakdown effects reducing the overall computing power whilst partially negated by the cessation of adaptive and monitoring calculations may cause serious delays in the production of control information. Calculations which are themselves iterative in nature may converge more slowly than expected and result in bottlenecks at a particular processor. Finally, any form of time-sharing with off-line programs, whilst being desirable at the higher levels of the computer hierarchy, will restrict response times following demands for data from the lower levels.

Queue Theory provides an adequate basis for a description of the patterns of data flow and is extended to handle the case when the balance between traffic intensity and service time is disturbed to cause an effective data loss. This structure is combined with elements from the Theory of Storage, likewise extended to deal with overflow, and moulded into a comprehensive system suitable for the analysis of on-line computer systems.

CONTROL SYSTEMS AND ALGORITHMS FOR A "STEEL - ROLLING PRODUCTS"MANUFACTURING COMPLEX OF A STEEL WORKS

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Described are methods and results of investigation of a operative plannig system and control with the use of CWM for main parts of a complicated ~~sixk~~ steel rolling mills complex. Discussed is the task of an operative planning for a very large factory with a complicated parallel - following structure of production, large number of coworking machines and different production processes.

Given are questions and algorithm cynthesis made for following control equations: monthly operative plan for whole complex, daily planning of all elements of parallel-following plant structures.

Algorithms are obtained with the help of linear programming apparatus, complicated question of mathematical logic and mathematical statistics meaning.

Shown and analyzed are results of test run of algorithmes on U W M computer center of a steel mill, formed are requirements for ECWM for similar systems.

Discussed is question of operative control of a large open-hearth furnace department of the plant. with full steel production process.

Given are process charakteristics and its connections with other plant departments.

Shown are some investigation results of working departments and use of a statistical simulation in studying of the object.

Structure and control algorithms of the system is described, including rail transport control, central department control central alloy feeding control and control computer.

Shown are investigation results of a plant control as for general service system, defined are system characteristics, formed are control rules.

Formal plant model as a general service system is given.

Shown are results of an industrialized - test exploitation on one of the steel mills.

AN APPROACH TO AUTOMATIC ADAPTIVE BATCH PRODUCTION SYSTEMS

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This paper outlines the difficulties involved in determining the optimum sub-goals for a fully automatic batch production system. The scheduling problem for general optimisation criteria is outlined, previous methods of solution in specific cases are discussed briefly and a heuristic method for solution proposed, balancing quality of solution against cost of computation. Computational experience of an experimental program is given against algorithmic specific case solutions.

The method is indicated to be useful in other control and optimisation problems.

The proposed method employs a graph theoretical approach where the graph traversed is the decision tree with nodes at each decision point. Values are allocated to each node according to the optimisation criteria and cost function. The method seeks the best route through the graph.

Should an overall optimum be required, the method will provide an economical starting point for the 'branch and bounds' algorithm to solution.

THE USE OF COMPUTER TECHNIQUES IN THE MANAGEMENT CONTROL OF A STEELWORKS

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1.0 The decision to use computers at The Park Gate Iron & Steel Co. Ltd. was made at a time when the Company was planning a major expansion in its production facilities. Computers were introduced to provide a planning service for the whole works, and in one crucial area to provide on-line control.

2.0 The system is based on three main magnetic tape files which record the Company's order book, work in progress and stocks of ingots and semi-finished steel. These files are updated 20 times each day with production information from the works.

3.0 Much of the information output by the computers is designed to help managers to have a better understanding of the activities of the works and to direct their attention into areas where their efforts should be concentrated.

3.1 Minute by Minute Control

Minute by minute control is concentrated in the primary mill. The computer system is designed to co-ordinate operators and automatic controls to obtain maximum throughput. This is achieved by a computer controlled display system operated from a production control centre. Information is given to the mill operators on cathode ray screens on which the computer displays instructions for ingots moving through the mill.

3.2 Day by Day Control

Day by day control is aided by the computer-based production planning system. The task of the production planning department is to find ways of grouping customers orders, first into casts by quality, and later into rolling batches by size.

3.3 Longer Term Control

The main files are summarised at weekly and monthly intervals to provide reports for accountants, metallurgists, sales forecasters, etc.

4.0 Development of the present systems is limited by the capacity of the computers, inaccuracies in shop floor data, and delays in obtaining information from the production departments. In order to overcome these problems, a development scheme is planned, which will replace the two central computers with one large computer with disc storage. Production messages will be input direct to this computer through 50 teleprinters located around the works.

CONSIDERING SYNTHESIS OF LIFTING REENTRY VEHICLE CONTROL SYSTEM STRUCTURES IN ATMOSPHERIC MANEUVER

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Consideration of the interaction of longitudinal and lateral motions of lifting reentry vehicle (LRV) is necessary for hypersonic flight even at comparatively small angles of attack and sideslip. Therefore it is of interest to investigate the set G of multivariable LRV control system providing independence or insignificant dependence of controlled variables or groups of them.

In this paper the problem of obtaining all the set G of the control system structures and selecting the best of them in the sense of control quality and simplicity of implementation is considered.

As the basis of structural representation of LRV control systems the graphs with no loops are chosen to make significantly easy the investigation of interconnections of LRV controlled variables and to allow obtaining the set of structures of the selectively invariant systems. Approach to analysis and syntesis of the whole control system is also simplified.

A number of the theorems for obtaining the set of the selectively invariant control systems is given. The set of the structural graphs S $\{S_1,..S_n\}$ the great-trees M $\{M_1,..M_e\}$ and the autonomous groups $L\{L_1,..L_k\}$ as the control system structures is determinated.

The formulas for obtaining a number of additional connections in the control system providing selective invariance of separate control variables or groups of them are presented.

Investigation of the set G $\{M,L,S\}$ of the hypothetical LRV control system structures allows to select the best structure in the sense of control quality and simplicity of implementation.

OPTIMUM INTERPLANETARY MIDCOURSE

VELOCITY-CORRECTION SCHEDULES

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Techniques are presented for predicting optimum midcourse fixed- and variable-time-of-arrival velocity-correction schedules. Certain limitations of the theory are pointed out, with suggestions for their removal by reformulation of the optimum timing equations. The theoretical results are compared to those of a simulation program which utilizes Earth-based radar and onboard sextant tracking data processed with a Kalman filter for two typical interplanetary transfers. It is shown that the agreement between theory and simulation improves as the amount of radar data is increased and that the theoretical optimum timing equations provide an accurate first estimate for generating interplanetary midcourse velocity-correction schedules.

OPTIMAL PARAMETRIC CONTROL FOR THE RE-ENTRY SPACE VEHICLE

by

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Atmosphering part of a space vehicle re-entry descent is considered. Disturbances affecting the space vehicle during atmosphering descent can be considered as a problem of stochastic initial conditions imposed on the vehicle's phase-coordinates during the re-entry moment.

As the control performance criterion, a dispersion of the circular deviation from the vehicle's landing points was chosen.

The vehicle control was assumed to be realized by variations of the vehicle attack and side-slip angles, given by linear combination of the phase-cooridinates deviations from the programmed ones. The last are determined in relation to the space vehicle trajectory.

A solution algorithm for statistic optimization problem with utilization of nonlinear programming methods is then considered. Some approaches enableing for considerable improvement of the optimization process convergence are also discussed.

Solution obtained for the given problem points out for a significant effectiveness of the proposed control law structure.

STOCHASTIC OPTIMIZATION OF SPACE SHIP REENTRY CONTROL IN ATMOSPHERE

A.G. Vlasov, I.S. Ukolov, E.I. Mitroshin

The authors consider questions connected with the synthesis of the autonomous system for controlling the distance of a spacecraft at the stage of its descent in the atmosphere. The overload, measured in the interconnected axes of the spacecraft, serves as the source of information, the list angle being the source of variable command.

The control system is being built by using the nominal trajectory. It is assumed that the circuit of the control system includes a board digital computer, with real requirements as to quick action and storage capacity.

The investigated dynamic process is described by the following system of equations, set at the segment $[0, T]$:

$$\dot{x} = X(x, u, t), \qquad /1/$$

$$\dot{x}_1 = A(x, u, t)x_1 + B(x, u, t)v + \varepsilon(t), \qquad /2/$$

$$y = H(x, u, t)x_1 + \xi(t), \qquad /3/$$

where /1/ describes the motion along the nominal /undisturbed/ trajectory, /2/ describes the disturbed /linearized/ motion, /3/ describes the obtaining of information on the current state of the disturbed motion according to the results of observation.

The frontier conditions at the ends are recorded in the form

$$x(T) \in \{x : q_k(x) = 0\}; \quad x(0) \in \{x : \gamma_i(x) = 0\}; \qquad /4/$$

$x_1(0)$ - is the vector of random variables with known characteristics.

It is necessary, for the dynamic system /1/, /2/, /3/ with frontier conditions and limitations, to minimize the function

$$M\omega[x_1(T)] \qquad /5/$$

where M is the sign of mathematical expectation; ω - scalar positive function, dependent on $x_1(T)$.

In considering separately the disturbed motion/ system /2/, /3/ as a stochastic problem of optimally controlling the final state /5/, one manages, byusing the concept of sufficient coordinates, introduced by R.A.Stratonovich, to break the block of the optimum control of disturbed motion into two independent blocks. The first of them is a block of optimum filtration, the second - a block of optimum regulator which is structurally invariable in relation to the dynamic system parameters /2/, /3/. This allows to consider the problems of programming the nominal trajectory and of ensuring its actual realization / system /1/, /2/, /3/ / in mutual connection with the use of the single criterion /5/.

ATMOSPHERE RE-ENTRY CONTROL PROBLEM

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(Moscow)

The paper deals with the problem of control of a space vehicle motion during the atmospheric re-entry with a parabolic velocity. It is supposed that the lift of the vehicle is small and the vehicle moves with the constant angle of attack. The roll angle of the vehicle is considered as a control function. The system includes DC.

The navigation problem is solved by using the measurements of three accelerometers installed on the stabilized platform. It is assumed that the density atmosphere deviation from standard distribution changes smoothly enough along the flight trajectory. It gives a chance to extrapolate the data for small enough period of time. The algorithm creates in case of emergency the reserve of controllability to compensate the predicted disturbances.

The control system produces for the nearest time interval the constant roll-rate which provides the desired downrange. The modulus of difference between produced and previous value of roll-rate is restricted. Such kind of rectrictions reflects the real possibilities of the control system implementation. It is supposed that after an interval of selection of constant roll_rate, roll-angle approaches to some specially nominated function of time. The nomination of this function reflects the process of adaptation of control system to atmosphere environments.

Some numerical results are presented to illustrate the effectiveness of the control algorithm and control quantity in case of large-scale atmospheric density variations.

STOCHSTIC PROBLEMS OF MISSILE DYNAMICS

Y.P. Plotnikov

A presentation is made of the methods of solving these problems of controlling the motion of the flying apparatus, for the solution of which it is not purposeful to separate the investigation of the programmed and disturbed motions. These problems may be called stochastic problems of rocket dynamics. One formulates the problem of optimization according to the single criterion of a determined programmed and a stochastic disturbed motions. This problem is solved by creating sufficient conditions of an absolute minimum of stochastic controllable systems. The latter conditions consist in a generalization for stochastic systems of the general form of the corresponding optimum conditions of V.F. Krotov's determined systems.

For the linear formof the stochastic disturbed motion the contrl law for solving the problem of optimization is obtained on a digital computer.

STATISTICAL SYNTHESIS OF OPTIMAL PULSE CONTROL SYSTEMS WITH REGARD FOR SYSTEM'S STRUCTURE CONTRAINTS

A.Ya. Andrienko

When working out board systems for automatic control of spacecraft, of great importance are the reliability requirements which become easier to fulfil in case of simple structural diagrams of control systems. For this reason it is purposeful to carry out a synthesis of the optimum systems with due regard for the limitations pu on the structure. Three types of such limitations can be indicated: limitation as to the storage capacity of the control equipment; limitation as to the number of devices reproducing the coefficients of the operation law of the control equipment; limitation as to the type of operations that can be made in the control equipment.

When a board digital computer is used in the control system it becomes rational to use sampling control laws.

The paper presents statistical methods of the synthesis of impulse systems with the said limitations being taken into account. These methods are presented as applied to terminal control systems. The limitation as to storage capacity is attained through the limitation of the volume of information, processed in the control equipment when the control signal is formed. In this solution of the problem the synthesis is carried out on the basis of the theory of statistical solutions and dynamic programming.

The limitations of the second type can be taken into account approximately as a result of the optimization of the programmed motion of sampling intervals of the impulse system.

As regards the synthesis of systems with limitations of the third type it is assumed that in the control equipment only algebraic operations can be made. The synthesis is carried out by using experimental methods of statistical linearization, effected by means of a digital computer with the number of the realization of control processes being limited.

As regards the synthesis of the systems with limitations of the third type it is assumed that in the control equipment only algebraic operations can be made. The synthesis is being carried out ~~xxthxthx~~ by using experimental methods of statistical linearization, effected by means of the with the number of the realization of control processes being limited.

OPTIMAL CONTROL SYSTEM FOR STATIONARY CIRCUMTERRESTRIAL SATELLITE ORBIT

A.A. Lebedev, M.N. Krasilschicov, V.V. Malishev

It is considered how to solve the technical problem of a synthesis of the optimum control system, designed for correcting the orbit of a stationary artificial Earth satellite (SAES) when it is put on the orbit and maintained in a set direction. It is proposed to use, for control, the measurement data obtained from tracking stations on the Earth.

When solving the problem of controlling on the basis of incomplete data one takes into account random errors in measurement and random errors in the realization of corrective impulses, both additive and multiplicative.

An analysis is made of the following questions:
choice of the control law of the optimum processing of information obtained as a result of the measurement; choice of the control law of optimum correction, which ensures the required necessary precision with minimum losses of energy; choice of the minimum number of measurements and frequency of measurement, necessary for the realization of the obtained control law of correction; determining of the optimum speed of launching the SAES.

To solve the problem the notion of sufficient coordinates and methods of dynamic programming is used.

In order to check a number of engineering admissions made when the problem was solved, the synthetized control system is being modelled by the statistical test method.

A block diagram of the control system and modelling results is made.

Simulation of distributed systems in chemical engineering

S. Bay Jorgensen and [illegible]

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Many units in a chemical plant are distributed systems [illegible] staged systems with distributed characteristics.

[illegible] model for a [illegible] of the element [illegible] the physical system are presented. [illegible] discretization of the different element simulation of the [illegible] with [illegible] inlet potential and flow in [illegible] element [illegible] possible. The static and dynamic [illegible] of the simulation with [illegible] to the different types of [illegible] systems. The relation between the [illegible] and accuracy with respect to flow, [illegible] are [illegible] on the results presented [illegible].

The [illegible] been [illegible] on the following [illegible] units: [illegible] liquid heat [illegible], liquid-liquid heat exchanger with counter-current [illegible] -liquid [illegible] bed. [illegible] frequency responses obtained [illegible] computation are presented.

The experimental [illegible] confirms the theory. With these re[illegible] to simulate dynamic behaviour [illegible] inlet potentials [illegible] a range of chemical systems with [illegible] to evaluate the accuracy before the [illegible] performed.

MODELS AND SIMULATION OF FIXED-BED TUBULAR REAKTORS

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This paper deals with a new mathematical model of a fixed-bed tubular reactor. This model takes account of a flowing and a fixed phase, which are connected by heat and mass transfer. Thus the reactor is described by two balances of energy and two of mass. In case of a very intensive heat and mass transfer the two-phase-model passes to the known diffusion-model. It is shown that the twophase-model can be simulated on the analog computer by the method of modale simulation. The results of simulating a fixed-bed tubular reactor in recycle-process are discussed. Finally the stability of the diffusion-model is analysed.

OPTIMIZING CONTROL OF HYDROGENATION PROCESS

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This paper deals with the optimizing control of the hydrogenation process of acetylene, so that the mole fraction of the intermediate product or ethylene is kept at maximum. The scheme of the optimizing control system is constructed as follows:

The mixture of hydrogen and acetylene is fed into a fluidized bed reactor with the constant mixing ratio and the small portion of the total inlet to the reactor is perturbed in the shape of M-sequence signal with a constant amplitude. Small portion of the outlet flow of the reactor is fed into a pipe packed with silica gel. Cross correlation function between the output signal from the flow detector attached to the outlet side of the packed pipe and the delayed M-sequence signal gives necessary information about the value of yield of product. The peak height of the cross correlation function appears as a good estimate of the local slope of the yield curve of the ethylene versus the inlet flow rate. The feeding rate of the inlet gas is so controlled as proportional to this slope by means of automatic equipments.

Theoretical study concerning stability of the optimizing control system and experimental study with a pilot equipment of hydrogenation of acetylene are carried out. Simplification of optimizing tactics is also discussed.

THE DESIGN OF A CONTROL ALGORITHM FOR THE PROCESS OF UREA PRODUCTION

L. Sutek, B. Frankovic

SUMMARY

The paper deals with the suggested system of optimal control of granulated urea production. The method by which the problem was solved, is introduced. The mathematic model is given and its direct application in the algorithm of optimal control. The system considers two purpose functions. Experiments were carried out on the hybrid computer and the results werw directly transferred to the control of the production process.

On the basis of attained results in operation it is stated that the suggested control system meets the given conditions and its rentability depends in the given case /for the manufactured amount of the product/ on the type of processor used.

The control algorithm of an ammonia synthesis reactor.

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The ammonia synthesis reactor is classified as a production apparatus with a very complicated inner structure. If optimal production conditions should be maintained during the operation of a reactor, it is necessary to use a control computer.

The basis for the control algorithm is the mathematical model of a production process. Theoretical static models /both exact and complex as well as approximate and relatively simple/ and dynamic ones were worked out. The both models were verified by experiments on the plant, the latter by using binary pseudorandom signals.

The results were used as a basis for optimal control obtained by dynamic programming.

AN ADAPTIVE MAN-COMPUTER CONTROL SYSTEM
FOR A CHEMICAL PLANT.

R.Tavast L.Mytus

An adaptive control system with a man as final decision-maker and computer as his adviser is considered. Stationary behaviour of a chemical plant is described by nonlinear model containing a vector of unknown parameters and based on hypotheses concerning the plant.

To the beginning of normal work of the system nonlinear simultaneous parameter estimates together with covariance matrix of residuals estimate are evaluated. Parameter estimates are corrected recursively during the normal work.

For each economical criteria from a finite set a stochastic optimization problem is formulated and solved by reducing it to a deterministic problem of nonlinear programming.

The computer provides man with information about the plant behaviour in the past, about the present state and recommendations for the future of the plant.

The system is put into operation in formaldehyd plant using Minsk-22 computer.

DETERMINATION OF THE SPATIAL STABILITY OF THE AXIAL FLUX SHAPE OF RE-ENTRANT FLOW GAS-COOLED POWER REACTORS WITH AUTOMATIC POWER CONTROL

By: R.L. Carstairs
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Conventional automatic control of steady-state power level in gas-cooled power reactors operates to maintain constant outlet gas temperature. The axial neutron flux shape is not controlled, and its spatial stability depends on the balance between neutron leakage and destabilising factors such as positive reactivity-temperature coefficients and xenon 135 burn-out. The spatial stability also depends on the control arrangements, and is affected both by the amount of automatic control rod group penetration and by the amount of penetration of coarse control rod groups.

For cores having a single coolant flow direction the effects of neutron flux shape and automatic or coarse control rod group penetration are well understood. For re-entrant flow systems with coolant flow in both directions the interactions between parameters are more complicated, and the spatial stability margin depends in addition to the features already mentioned on the re-entrant to forward flow ratio and the heat transfer between the flow paths.

Transient solution of the space-and-time variant distributed parameter system has been found to be too cumbersome for parameter survey work, although valuable for reference. The present paper discusses a representation of the re-entrant flow system in simplified form which permits iterative trajectory methods of solution; these are extremely rapid and economical. Results for a typical advanced gas-cooled power reactor are presented, discussed, and compared with transient solutions of the distributed parameter representation, showing good agreement.

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Mathematical models for the dynamic behaviour of steam-heated heat exchangers for steam flow or condensate flow regulation

Because heat exchangers belong to the class of systems with distributed parameters, the frequency responses are transcendental functions and are to complicated to use in a simple manner for practical cases (designing of control loops, simulation in analog or digital computers). Therefore it was necessary to develop simplified mathematical models for steam-heated heat exchangers. The models are simple to use and describe the dynamic behaviour with an accuracy sufficient for practical purposes.

The models are shown and compared for two different valve locations. In the case of regulation on the steam side the control valve influences the steam flow while in the case of regulation on the condensate side the control valve influences the condensate flow. For regulation on the steam side it is necessary to distinguish two different models according to over critical and under critical pressure ratio across the control valve.

The control behaviour is compared for both cases of regulation with the aid of examples of heat exchangers. Regulation on the condensate flow shows the disadvantage of greater time constants. However if the velocity of disturbances is small, sufficient quality of control with condensate side regulation can be obtained. But if the velocity of disturbances is great, steam side regulation is preferred.

The dynamic behaviour of steam-heated heat exchangers in dependence of load is also shown and compared. For the case of low loads there is danger of instability.

Measurements with industrial heat exchangers confirm the theoretical investigations.

THERMAL TRANSFER FUNCTIONS FOR A HOLLOW CYLINDER WITH INTERNAL HEAT GENERATION

by E. Cosimo, S. Petrarca

The problem of transient heat generation and transmission along the radius of a hollow cylinder is solved, assuming its diffusivity and conductivity are constant.

The two cases are taken into account that cylinder's surfaces are in contact with either two claddings or two fluids; in the latter case the dependence of convection coefficients on flow rates is linearized.

Transfer functions from boundary temperatures, thermal power density and flow rates, to the cylinder's temperature are obtained by Laplace's transform. In particular, transfer functions to average and surface temperatures are given; however, it is possible to deduce from given formulae the temperature of any point in the cylinder.

The problem is treated in terms of three non-dimensional parameters:

$R = R_i/R_e$, internal-to-external radius ratio;

$H = h_i/h_e$, heat transfer coefficients ratio;

$M = R_e h_e/k$, Biot's number for external surface;

and of the non-dimensional variable:

$a = i\, R_e \sqrt{s/\alpha}$

(s = Laplace's variable, α = diffusivity).

Heaviside's series expansions of transfer functions are given, and it is shown that they are approximable by a small number of terms. The poles of transfer functions are found by solving the equation:

$$\left[HMJ_0(Ra)+aJ_1(Ra)\right]\left[MN_0(a)-aN_1(a)\right]-\left[HMN_0(Ra)+aN_1(Ra)\right]\left[MJ_0(a)-aJ_1(a)\right]=0$$

(J_0, J_1, N_0, N_1, Bessel functions).

The results of this work are applicable to fuel rods of many nuclear reactors, to metallic tubes heated electrically or by induction, to heat exchangers' tubes, to pipes with hot fluids; they may be of use whether in studies of thermal dynamics of installations or in the analysis of thermal stresses in individual components.

Summary of the paper proposed by Mr. G. DAVOUST
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DETERMINATION OF HEAT-EXCHANGER DYNAMICS ON THE BASIS OF THEIR STRUCTURAL CHARACTERISTICS

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The determination of heat-exchanger dynamics for perturbations of various origins usually requires long and delicate testing performed on an installation with different operational conditions.

In this study, this identification is based on the theoretical method developed by Prof. PROFOS. In the case of modern steam plants, it permits to determine the transfer functions linking the exchanger outlet temperature to the following three main inlet magnitudes : steam temperature at the input of the exchanger, the steam flow and the calorific perturbations of outside origin. This determination is made extremely easy through the exclusive use of nomograms and graphs. It results in transmittances of simple polynomial forms of the type

immediately usable for the development of regulation circuits by conventional methods. These graphs and curves were plotted for French thermal units of I25, 250 and 600 MW nominal characteristics I25 bars - 545° C - 545° C and I63 bars - 565° C - 565° C). Their use requires only the knowledge of the structural characteristics of the exchanger and of its operational conditions.

It thus becomes possible, when designing a new power plant, to predetermine the best adapted steam-temperature regulation circuits and, on an running installations, to improve the functioning of a circuit without perturbing the operation of the plant.

ON THE DYNAMICS OF HEAT TRANSFER BY GASES THROUGH PIPES AND C[illegible]

By

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The problem is encountered for instance in a cooling channel of a gas-cooled reactor where along the channel heat is added or in the heat transmission of teleheating where pipes are assumed to be isolated against heat losses. Starting from the conservation equations of mass, momentum and energy and the equation of state of ideal gases the static equations are solved rigorously and the dynamic equations are linearized. Gravity and friction are not accounted for. Heat conduction is neglected against convection and the specific heat of the gas at constant volume is assumed to be constant. The analysis is performed assuming density, velocity, pressure and temperature of the gas to be constant in any cross-section of the channel. The case of constant heat addition along the channel is treated in more detail.

DYNAMIC RESPONSE OF CROSSFLOW HEAT EXCHANGERS

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Dynamic response of crossflow heat exchangers with both fluids mixed, one fluid mixed and both fluids unmixec is analysed.

The governing differential equations for these three cases are formulated and non-dimensionalized as distributed systems and the transfer functions to temperature changes of the inlet fluid are obtained by Laplace transform technique.

The results are shown by frequency responses both for the case in which wall capacities are neglected and for the case in which wall capacities have predominant effect.

The numerical results for non-dimensionalized parameters are compared.

SYSTEMS WITH VARIABLE STRUCTURE IN MULTIDIMENSIONAL PLANTS IDENTIFICATION AND CONTROL

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The paper discusses the principles underlying the construction of systems with variable structure to be used in control of plants described by differential equations of the form

$$\frac{d\bar{x}}{dt} = A\bar{x} + B\bar{u},$$

where $\bar{x} = (x_1, \ldots, x_n)$ is an n-dimensional vector that characterizes the state of the system; A is an $n \times n$-dimensional matrix with constant or variable elements a_{ij}, B is an $n \times m$-dimensional matrix with constant elements b_{ij}, $\bar{u} = (u_1, \ldots, u_m)$ is an m-dimensional control vector.

A procedure for changes in the system structure is chosen such that the order of the differential equation for motion decreases successively; this gives the desired dynamic properties of the system. Cases are described where data on the parameters of the control plant are needed for the procedure obtained to be implemented. For these cases additional identification loops are constructed that are based on the principles of systems with variable structure; where certain conditions are met, the control actions in those loops are shown to have a functional relation to the plant parameters.

By appropriate selection of the number and the structure of these loops and by measuring controls therein we obtain a set of algebraic equations whose solution is the set of the unknown parameters. With this information the procedures obtained for control of multidimensional plants are implemented.

STRUCTURAL PROPERTIES OF DYNAMIC SYSTEMS

M. Vukobratovic
R.S. Rutman

The relation between parametric invariancy and zero sensitivity is established.

In addition the topological formula for the sensitivity of the systems which is described by linear signals flow graphs is given.

Necessary and sufficient conditions for zero sensitivity are derived in analytical form. The paper contains also algorithms for the synthesis of invariant systems of the second and third order.

The relation between zero sensitivity and unobservability is considered as well as controllability conditions based in the perturbations of the parameter vector.

NEW DEVELOPMENTS IN THE T.C.F. METHOD FOR MULTIVARIABLE CONTROL SYSTEMS.

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At the Symposium on Multivariable Control Systems sponsored by IFAC and held at Düsseldorf, Germany in October 1968 a paper on Tetransfer Control Functions (T.C.F. Method) was presented which describes an improvement in Matrix Theory and its application to linear time-invariable systems of multiple variables and multiple control feedbacks.

The approach consists of a class of structural matrices with a unitary determinant, that is invariant in a 2n dimensional space with regard to connections that permit the passage from $2n_1$ to $2n_2$ dimensions for any whole number n. For n = 1 the Tetransfer Control Function for two dimensions was defined. This function is the basic cell by means of which matrices of any complexity can be built in an easy way.

In this paper this method is completed by means of new developments and at the same time attention is paid to the question of obtaining the required answers from a system by the adequate use of control vectors which act on the system together with the normal inputs of the controlled system which are generally considered as perturbations.

Finally the possible application to an Analog-Digital system of computation is outlined.

ON PROBLEM OF INVARIANT SYSTEMS SYNTHESIS

V.V. Vielichenko

In this paper, synthesis of corrective circuit which assures invariability of given quality of nonlinear object output index disturbance, is solved.

It is shown, that synthesis question solution, is assured by prognosis of undisturbed moovement of the system and in the case when there is full integral of undisturbed system.

Method of solution uses formed during the work, necessary and at the same time satisfactory conditions of invariability, obtained basing on optimal theory method and followed during the work technique of big variations of the function.

Given are egzamples of correcting circuits synthesis.

OPTIMUM CONTROL OF A CLASS OF RANDOMLY-EXCITED DISTRIBUTED-PARAMETER SYSTEMS

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An optimum control law is derived for a class of randomly-excited distributed-parameter processes whose response can be expressed in terms of a Green's function. An analysis is presented for the randomly-excited diffusion process, but the results are readily extended to higher-order processes. Using a backward operator derived elsewhere and properties of distributed Markov processes, the well-known separation theorem of randomly-excited, lumped-parameter processes is extended to the distributed-parameter case. A numerical example of the control of a diffusion process with noisy observation data is presented and the problem of locating a pointwise sensor is also considered.

ON CONTROLLABILITY IN A PURSUIT PROBLEM

N.A. Babakov, D.P. Kim

The problem is being analyzed of the spatial pursuit of point A by point B under following conditions. The pursued point B is moving on a steight line. The pursuing point A has a constant speed. Angular velocities of a limited value serve as the control of point A. Velocity V_A of the pursuing point A is smaller than velocity V_B of the pursued point B /V_A V_B/.

In connection with the latter condition it is evident that point A cannot under all initial conditions reach a certain E-vicinity of point B. Then the problem arises that is considered in the paper, namely the problem of determining the conditions of controllability, that is conditions which, if fullfilled, will allow point A to reach, in the process of pursuit, point B.

This spatial condition of the initial conditions of pursuit marks out the field of controllability, and the problem under consideration may therefore be formulated as the problem of determining in space the initial conditions of pursuit of the controllability field.

It is shown that the condition of controllability is fullfilled when the extremes of the function correspond to definite inequalities. The determination of the expression for the extreme values of the said function is connected with the necessity to solve a /the control vector for point A being /non-linear problem of optimum control. Thus the initial problem of determining the conditions of controllability boils down to the variation problem, more exactly, a two- and three-point variation problem with a movable right end of the trajectory. The said variation problem is solved by means of L.S. Potryagin's maximum principle. As a result, the structure of optimum control was found and a diagram of solving the original problem given.

DYNAMICS OF THE TETHERED ASTRONAUT MOVING TOWARD THE SPACECRAFT AND AN APPROACH TO SYNTHESIS OF SPACECRAFT CONTROL BASED ON A THEORY OF THE VARIABLE-STRUCTURE SYSTEMS

V.N. Soshnikov, G.M. Ulanov

The author considers the questions of an analysis of the incontrollable system, substantiates the indispensability of control to attain the set quality of the process of return and put forth the principle of building a control system allowing to ensure the optimal, in a sense, process of the cosmonauts returning to the spacecraft.

For the adopted system model the possible positions of equilibrium are investigated, their dependence on parameters and initial conditions is considered, the bifurcation values of parameters are determined.

As regards practical interesting positions of equilibrium a linearized equation is built, one which represents a linear differential equation with Fuchs type variable factors. The properties of the equation obtained are investigated by means of asymptotic ideas near special points and by means of the Sonin- [illegible] theorem, in quality [illegible], throughout the time interval. By way of modelling on a digital computer the coincidence of the properties of the non-linear and the built linear equations was established.

To obtain qualitative evaluations an asymptotic solution of the linear equation was built. By means of modelling evaluations were obtained, which allow to establish the precision of the asymptotic solution.

On the basis of the results attained the properties of the process are investigated of the cosmonaut's return to the spacecraft and the conditions are determined in which the process of return in the incontrollable system possesses the set quality. The practical unfeasibility of the conditions obtained permits to substantiate the indispensability of control, the most simple type of which, from the point of view of realization, is the relay control of the angular motion of the spacecraft.

An approximative equation was obtained, which describes the return control system that includes a parameter assuming two fixed values and changes boundways when passing a certain hypersurface in the phase space of the system. In these systems which have been named variable structure systems, so-called sliding duties may arise, which allow to obtain a high quality of regulation. This idea it is proposed to use for the synthesis of a high-quality system of the cosmonaut's return to the spacecraft, by means of a rational use of the hypersurface for switching the motors controlling the angular motion of the spacecraft. The basic possibility of a synthesis of this system is shown.

MEASUREMENT OF FORCES AND MOMENTS FROM A THRUST VECTOR CONTROLLED ROCKET ON A FIVE COMPONENT TEST STAND

Ping Tcheng* James W. Moore**

This paper describes the analysis and design of a five component test stand for the purpose of testing thrust vector control systems on rockets in the 3000 pound thrust range. Present stands have mechanical resonance in the range of 15 to 30 Hz. The specifications here called for a relatively flat response to 100 Hz. A feature of this system is a set of flat hydrostatic oil bearings which support the rocket. These allow for thermal expansion parallel to their surface and provide very stiff support and heavy damping perpendicular to their surface. Thorough frequency response testing shows the bearing to behave as an excellent first order filter. A digital computer study using the actual test data from the bearing shows excellent overall system response to 100 Hz.

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TIME-OPTIMAL NUCLEAR ROCKET PROPELLANT START-UP WITH THERMAL STRESS CONSTRAINTS BASED ON DISTRIBUTED PARAMETER MODEL

by

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and

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Core and propellant temperature of a solid fuel element nuclear rocket are described by a pair of coupled partial differential equations depending on the power distribution and the propellant flow rate; the latter is taken as the independent control variable. The thermal stress in the core is given by a product of state and control variables.

The set of partial differential equations is solved in integral form for core temperature, propellant temperature and the difference between them. These integral expressions are used in the solution of the following minimum time problem: Find the control program which increases the propellant flow rate from a given steady-state level to a fixed higher level in minimum time without exceeding a certain maximum tolerable stress in the core. This problem is shown to be equivalent to a certain fixed final time problem which requires the minimization of a functional subject to an integral equation and an integro-differential inequality constraint. To the authors' knowledge, optimal conditions for such a problem are not yet available in the literature. They are derived and used for obtaining the minimum time control law in closed form.

A computer algorithm for the numerical implementation is derived. Numerical results are given for different power distributions.

SPACE VEHICLE DATA SYSTEM SYNTHESIZER

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Until quite recently, on-line computer systems were usually phased into an existing operation in "piggy-back" fashion. That is, the primary non-computerized control system remained operational (with no production, or other penalty) until the automated system was debugged in an off-line mode. Changeover was accomplished at some convenient point with the original control system serving as backup to the computerized system.

Today, following general acceptance of automated control systems, the computerized (and now primary) process control or checkout system (which can be considered as open-loop process control) must be developed simultaneously with the process and instrumentation systems.

The Space Vehicle Data System Synthesizer (SVDSS) addressed the problem of independent program testing by realistically simulating the system to be controlled (or monitored) and its associated instrumented outputs, whether analog or discreet, prior to its existence as a real-world system. Data streams are produced which duplicate the data streams anticipated from the proposed functional system.

When considering a system in a checkout or process control environment, emphasis shifts from accurate representation of the physical elements of the system to accurate representation of the control and test elements of the system. For this type of environment a high-level language is required which has attributes of standard.digital - analog simulation languages in addition to extensive discrete (logical variable) handling capability, operator/math model communications and data formatting facilities. By combining these features with a basic digital - analog simulation language, the Data Synthesizer provides a tool for designing and testing checkout and process control systems, prior to the existence of the primary system.

In summary, the Space Vehicle Data System Synthesizer, a software system initially conceived for and applied to space vehicle systems, has potential application in other areas of scientific endeavor. Earth resources and physiological sensing system output simulation are but two. Other areas are being explored.

SUBOPTIMAL CONTROL OF 2. ORDER PLANTS WITH TIME-VARYING COEFFICIENTS

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Considered are 2.-order control processes with constant coefficients. We want to determine an admissible control u ($|u| \leq u_o$), so that the functional $\int x^T Qxdt$ is minimized, beginning from a specified initial state x_o. For two sets of boundary values the switching curves are defined in the phase plane by computing point by point backward in time. For the first set of values one is getting curves, very good approximated by straight lines. The signifying values of these lines are functions of the coefficients of the plant. Beside this we find a singular control. The origin of the phase plane becomes a saddle point.

Now, after the optimal steering, a suboptimal control with two regions of switching in the phase plane is defined. The control's efficiency is shown on the example of the damped oscillator.

With only few modifications you may use this control system for a 2.-order plant with time varying coefficients. The coefficients being periodical functions, it is possible, to compute for any combination the signifying switching curve. Thus, for the control system, one gets switching lines with time-varying coefficients. The pitch moving of a satellite is controled with this system. The satellite moves on an elliptic orbit in the gravitational field of the earth.

DYNAMIC BEHAVIOR OF A LINEAR THRESHOLD ELEMENT WITH SELF-ADJUSTING WEIGHTS

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This paper presents a linear threshold element in which each weight changes automatically following a certain rule of growth. An analysis of its dynamic behavior is described together with some simulation results. Possible applications of the element are also discussed.

The element is basically a summing device. Its output y(t) is a weighted sum of its inputs $x_i(t)$, $i=1,2,\ldots,N$, i.e.,

$$y(t)=\sum_{i=1}^{N} w_i(t)x_i(t).$$

The inputs $x_i(t)$ are assumed to be zero-mean signals, but not restricted to binary signals. The weights $w_i(t)$ are adjusted automatically according to the differential equations

$$T\frac{dw_i(t)}{dt}+w_i(t)=ax_i(t)\operatorname{sgn}\left[y(t)\right], \qquad i=1,2,\ldots,N.$$

It should be noted that threshold function is used just for the weight adjustment and the output is the weighted sum itself.

A detailed investigation of the solutions of the equations above shows that the element has a tendency to separate its inputs into a "spectrum" or a family of orthogonal components and to pick out the component of largest power for its output. This property enables it to perform a variety of types of information processing such as majority decision logic, data storage, pattern dichotomy and signal filtering. These theoretical results are verified by some simulation experiments on an analog computer.

AN ADAPTIVE AUTOMATON CONTROLLER
FOR DISCRETE-TIME MARKOV PROCESSES

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The computation of an optimal feedback controller characteristic for a nonlinear stochastic system may be facilitated by the use of a stochastic automaton as a system model. A problem of particular interest is that of a long duration stationary Markov process in which the state is observable but the process dynamics and disturbance characteristics are initially unknown. The determination of a suitable control algorithm, in the form of an adaptive automaton in the feedback loop, is considered in this paper for such a process.

Since the algorithm is to be used on-line to perform simultaneously the functions of estimation and control, it must constitute an efficient convergent multi-stage dual control strategy. It is shown that an existing method for dual control of repetitive single-stage stochastic processes may be extended to apply to the present case. A method is introduced of calculating successive policy estimates recursively, so that the task of updating the estimated optimal feedback policy at each stage of the process is rendered feasible. The application of the automaton controller is illustrated by the simulated adaptive control of a nonlinear conditionally stable heat treatment process disturbed by multiplicative noise.

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A Digital Controller for Process Industries with Adaptive-Type Behaviour.

It has long been felt that the development and use of d.d.c. has too closely followed the path of classical linear control theory. Nearly all the applications of computer control use standard two or three term algorithms which are the digital equivalent to their analogue counterparts. Only recently has a transform theory been used to apply modern theory to the control of large plants.

The difficulty here is that it is necessary to be able to define plant dynamics accurately which is often difficult and also to incorporate the fact that process conditions change.

On-off control is known to be largely insensitive to process change and the work described here uses a digital computer to carry out this type of control. In many industrial applications it is possible to drive a valve in an on-off mode at a high enough frequency that the plant acts as a filter at the sampling frequency.

Linear switching lines in the phase plane are chosen so that even in the worst case of process change the average response still approaches the desired state along the same exponential trajectory. Up to second order cases have been examined including simulations of potentially unstable chemical reactors, and stable responses were always obtained. Plant start-up and shut-down are catered for since large errors present no particular problems.

The choice of controller coefficients is not a difficult one to make and care need only be exercised over the choice of sampling frequency with respect to plant time constants, in that sampling time must allow sufficiently good resolution of the system.

SIMPLE METHOD FOR THE RAPID SELF-ADAPTATION OF AUTOMATIC CONTROLLERS IN DRIVE APPLICATIONS

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Summary

The author describes a method of adapting the controller gain automatically to the controlled system and, at the same time, to the frequency range of the input signal.

A particularly simple case of the method in question is logarithmic control which, however, can only be used for certain types of controlled system.

The application of the method is described by way of two examples taken from the field of drive engineering.

ON SELF-ADAPTIVE SYSTEMS FOR MEASURING REAL TEMPERATURES WITHIN OPTICAL RANGE

D.A. Svet

Uncompletness of radiation energy spectral tightness at unknown radiation ability equation system does not permit for receival of true temperature optimal automatic control.

Studied schemes of signal nonlinear transformation from spectral radiation components, permits for using of excess informations to construct a program, which can be used for selftuning of automatic measuring system.

Realization of discussed method by self-tuning automatic systems permits solving of given task by quite simple technical means at uninterrupted radiation spectre.

All this opens new perspectives for automatic control of some types of plasm.

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ADAPTABLE REGULATION SYSTEM OF TEMPERATURE OR HUMIDITY IN AIR-CONDITIONED OBJECTS

S u m m a r y

Both theoretical and experimental research of dynamic characteristics of air - conditioned industrial objects have proved that outer disturbances (e.g. change of outer temperature) influence the dynamic parameters of the objects and in particular the response time to time - constant ratio (T_o/T).

Assuming that the character and direction of the investigated and quoted in this paper dependence $T_o/T = f(\vartheta_z)$ is similar in all cases, the thesis of effectivenes of applying of an adaptable regulation system of temperature and humidity in open objects has been put in. The adjustment of controls should be tuned to varying dynamic conditions of the objects.

The adaptable on - off controller of temperature and humidity, designed by the author of this paper for railway, shipping and industrial purposes, has been used for the analysis and formulating of adaptability to conditions. It has been proved that the amplification coefficient Kp^* of the controller is a function of outer temperature and the conditions have been given which it adapts automatically to the changing characteristics of the object. The range and course of changing adjustment coincide with optimal adjustment of PI or PID controller, according to the criterion of aperiodic course and minimum response time t_p.

In the paper the co - operation of the controller with a single or several thermometers or contact hygrometers has been analysed. It has been proved that the co - operation of the controller with several thermometers or contact hygrometers enables on one hand fixing of mean measurment impulses, on the other hand a non - linear progressive rise of amplification coefficient Kp^* depending on the value of deviation $U.^*$ This interdependence bears a stabilizing effect upon the action of the regulation system in the range of strong disturbances.

SOME SYNTHESIS PROBLEMS ADAPTIVE CONTROL SYSTEMS OF STATIONARY RANDOM PLANTS

V.I. Ivanenko, D.V. Karachenec

Discussed are solutions to the task of statistical synthesis of automatic optimalization /SAO/ of mass-changing system settings, based on application of statistical theory solution. For chosed SAO some results of A. Feldbaum dual control theory, are used.

Two typical mass-changing settings are considered:

- rectification column for debenzolizing working without separation of sideproducts,
- steam column.

Process efficiency in debenzolizing column is judged by process costs in a time unit

$$W = \alpha_L \cdot L + \alpha_d \cdot / 1 - x_d /$$

at condition:

$$x_w \leqslant X_w^x \cdot \text{rde} \quad \alpha_L \quad \alpha_D$$

X_w - constant, L - phlegm expediture, x_d, x_w - bemol concentration in the destillate and column.
Process effiecency index for steam column is shown too.

As a controlling actions for rectification column, tasks for temperature regulators of the "control" discs of the exhaustive and stregthening sections are choosed.

Expediture of steam directed to the bottom of the column, is a controlling action for steam column. Main disorder in both cases being expediture and composition of feeding. Changing of feeding composition happens in time to be a discrete "markow" process.

Mathematical models of the columns are used, which define dependance of offiecency indexes from controlling and disorder actions. Obtained results are used for building of, SAO structure schemes: steam column feedback system and system with disorder compensation for rectification column.

Quality grades for SAO are introduced. Synthesis of the system with disorder compensation is made by the way of minimalizing of the relative risk, which represents itself mathematical expectance of process effiecency index. For limitation of $x_w \leq x_w^*$, jump and regulator functions of "penalty" are used. For chosed systems functional Bellman equation for risk is obtained. Synthesis of optimal and suboptimal SAO is studied. Asymptoties of control process in the systems is studied. For synthesis of closed suboptimal SAO, where occures active storing of informations, algorithm is proposed, which doesn't need solving of the task of dynamic programing. Simulation of synthesed SAO was made on ECWM and quantity estimations of their economic efficiency were obtained. Ways of possible use of statical synthesis SAO on other types of mass changing settings, are shown. An example, when task of automatic optimalization of mass-changing process is practically impossible, is shown. With this there is no need for special optimalization arrangements, and all control system can be much simplified. Solution of SAO synthesis task of rectification column is used for debenzolizing columns in Dneprodzerjinkii chemical factory and results are used for practical introducing of the system.

CONTROL OF CYCLIC DISTILLATION

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A simulation study of cyclic distillation on a digital computer gives insight into the control problems associated with cyclic processes. A mathematical model demonstrates the experimentally observed hydrodynamic characteristics of the process over one cycle intervals.

Of the systems studied, the most stable situation results when the reboiler and condenser are physically isolated from the column during the liquid flow period. The conclusion is also advanced that regulation of the tray liquid level is required to insure the satisfactory operation of cyclic distillation.

CONSTRAINT CONTROL ON DISTILLATION COLUMNS

by

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In the design of a distillation column less favourable conditions are assumed than prevail on average during actual operation. For instance the condenser is made so large that the design throughput is still guaranteed under conditions of hot cooling water and when there is dirt and scale inside the tubes. For most of the time in actual operation, however, conditions are not as severe as this and the condenser has surplus capacity. By utilizing this surplus capacity the column can be operated at a lower pressure. The relative volatilities of the components of most hydrocarbon mixtures increase with decreasing pressure, making separation easier at lower pressure. Hence, less reflux and consequently less reboil heat are required to keep products on specification. Furthermore, the load on the trays decreases with decreasing column flows, which opens up the possibility of increasing product purity, product yield and/or throughput. Another degree of freedom in this respect is the distribution of heat over reboiler and feed-preheater.

This paper deals with control schemes which automatically keep the column at the optimum conditions. These conditions change with column throughput, cooling water temperature, etc. As an example the constraint diagrams and a constraint control scheme for a de-isopentanizer are given. The control scheme is not very complicated and can be realized by conventional means.

OPTIMUM BANG-BANG OPERATION OF TWO COMPONENTS DISTILLATION COLUMNS

F. De Lorenzo, G. Guardabassi, A. Locatelli, V. Nicolò, S. Rinaldi(°)

It is suggested that reflux should be periodically varied to better column operation. A bang-bang operation of a two components distillation column is investigated in order to achieve minimum mean reflux for a required distillate concentration.

The optimization problem consists in the choice of the two reflux levels and of the time intervals in which they are applied. Some general properties of such a problem are shown, owing to which the task of finding the optimum in a four-dimensional space is reduced to that of finding the optimum in a two-dimensional space. The discussion of a particular case and some concluding remarks can be found at the end of the paper.

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PREDICTIVE AND FEEDBACK COMMAND OF AN INDUSTRIAL DISTILLATION UNIT

by

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SUMMARY

The paper presents results of theoretical and experimental research of the "real time" control of the superfrationate column by a digital computer when manual control of the column required hitherto very accurate operations.

The goal of the automatic control is to assure fixed production quality, particulary in transient processes as well as to ensure optimal static performance of the installation /economical criterion/.

Static and dynamic models were determined on the ground of the theoretical studies and on the experimental tests. In this way a high precision has been achieved with relatively small number of the experiments.

The models were introduced to the computer storage.

Then, the open-loop dynamic control, utilizing the process' knowledge based on the a priori model was developed. Using this, the closed-loop control was imposed to compensate errors resulting from unmeasurable disturbances and from the model's inaccuracy.

The resulting control structure permits for best utilization of the available information, while establishing proper foundations for static optimization.

Afterwords, the system activating as well as issueing quantitative results have been presented.

The final results are quite satisfactory as steadiness of the process respons obtained issued in enlarging of the maximum production from 95% to IIO % of the nominal one.

A MATHEMATICAL MODEL AND OPTIMIZATION OF THE PHENOL FORMALDEHYDE RESIN POLYCONDENSATION PROCESS

E.G. Dudnikov, G.P. Maikov, P.S. Ivanov

Polycondensation of fenolo-formaldehyde pitches process based on quick pitch extraction from reaction region during it forming, was followed. Reaction of polycondensation takes place in the presence of a catalyst /hydrochlorie acid/ in multisection reactor of changeable action at atmosferic pressure and boiling temperature of reactive mixture of 100°C. Special feature of this process being great extraction of fenole and formaldehyde by the pitch.

Following equations were obtained:

$$\frac{An - 1}{Zn} = 1.14 \cdot A_n^{1.16} \cdot B_n^{08}$$

$$\frac{B_n - 1}{Z_n} = 1.69 \cdot A_n^{0.4} \cdot B_n^{1,36}$$

where $Z_n = T_n \cdot D_n$; A, B, D corresponding fenole, formaldehyde and catalyst, concentration; T - overage time. Index n means section number. Viscosity is a very important parameter, defining quality of pitch.

Dependence of pitch viscosity in n - th section from main process parameters, was found as regres equation. Basing on obtained equations, catalyst distribution was determined as well as overage timing for three section reactor of ideal mixing, minimalising given concentration of fenole and formaldehyde on their outgoing from reactor. At the same time problem of optimal distribution Z_n by dynamic program method, was solved. Overage staying time and catalyst distribution was choosen in such a way that their output was equal to optimal Z_n. It should be noted, that for several chemical processes, where chemical reaction constant, proportional to catalyst concentration / $K = K_o \cdot D_n$ /, distribution Z_n optimalization is necessary. For those processes, question of optimal distribution of overage staying time /volume at given output/, doesn´t have any sense, it means that it is more economic /in most of the cases/ to make reactors of the same volume, trying for better results by corresponding treatment with catalyst. Question of the optimal number of sections, was answered by dynamic program method considering cost of looses on enlarging of total reactor volume.

OPTIMAL CONTROL OF FLUID CATALYTIC CRACKING PROCESSES

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An investigation was made of the applicability of optimal control theory to the design of control systems for nonlinear multivariable chemical processes. A hypothetical fluid catalytic cracking process was selected as a typical representative of such a chemical process and was used to test and evaluate alternative approaches to the problem.

Mathematical models describing the dynamic behavior of the process were developed from unsteady-state heat and material balances about the reactor and regenerator. The models utilized semiempirical equations to describe the kinetics of the cracking and carbon burning reactions. The dynamic models were used to simulate the process on a digital computer. The simulations predicted most of the important dynamic characteristics that have been attributed to commercial units.

A new approach to the design of control systems for highly nonlinear multivariable chemical processes based on optimal feedback control theory was demonstrated for the design of a control system for the hypothetical fluid cracking process. In the feedback control law which resulted, the regenerator temperature is controlled by the air rate and the oxygen level is controlled by the catalyst rate. This control scheme is quite different from that which is typically used in refinery operation where the reactor temperature is controlled by the catalyst rate and the oxygen level is controlled by the air rate. The performances of this new control scheme was demonstrated by dynamic simulation to be significantly better at controlling the hypothetical cracking process in the face of disturbances than was the conventional control scheme.

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ANALYSIS AND DESIGN OF 200 MW BOILER-TURBINE UNIT CONTROL SYSTEMS THROUGH ANALOG AND DIGITAL SIMULATION

The paper describes the simulation approach which has been applied in the design of control systems for a coal fired 200 MW boiler-turbine unit with a boiler of natural circulation rated at 650 t/h, 138 at, 540/540°C.

The complex dynamic model of the unit was linearized at 100% load point forming a small oscillation model adequate for control systems analysis.

The following control systems have been investigated:

a/ steam pressure control circuit with PI or PID controller operating on pressure error alone and using additional rate anticipation from steam flow, turbine throttle valve position or drum pressure;

b/ superheated steam temperature control circuit involving four desuperheaters /water sprays/ operating in simple and cascade control subsystems with steam flow, fuel flow or throttle valve position anticipation;

c/ reheated steam temperature control circuit with gas damper and spray water injection based on a new control philosophy.

The steam pressure and superheater-temperature control systems were investigated on an analog model and the reheat temperature circuits by use of digital simulation.

OPTIMUM CONTROL OF A BOILER

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The work presented here has as its aim the study and realization of the optimum control of the steam pressure channel of a boiler. We have replaced classic control by a control implemented according to Pontryagin's maximum principle using a quadratic criterion and a very simplified model for the process. Calculation on the one hand and experiments carried out in simulation and real operation on the other hand, under the influence of a disturbance which is here a set pressure function applied at any moment, have given concordant results. In particular for this non autonomous problem,
calculated and measured in simulation correspond to one another perfectly and the control results in certain cases in a predictive control.

The realization of this control should now be generalized in the case of two state variables, that is either steam pressure and overheat temperature, or steam pressure and combustible feed and in this case the problem becomes complicated by the presence of a constraint on this latter component of the state vector.

COMPARISON OF DYNAMICS BETWEEN NATURAL CIRCULATION BOILER AND FORCED CIRCULATION BOILER

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H. Ohno **
K. Sagara**

An allowance for load fluctuation of a boiler has become important to the regulation of a power system. In connection with the allowance, the dynamics of different types of boiler is discussed in this paper. One is a natural circulation boiler and the other is a forced circulation boiler of 75 MW nominal rating respectively. As these two boilers serve for the regulation of power system which have the load of electric railway in the suburbs of Tokyo, they are disturbed with a random load fluctuation of which power spectrum has a large amount of 2 - 3 minute periodic components.

Moreover, the boilers are required to shut down in midnight for the reason of no train running. The experiments have been carried out to evaluate the allowance for load fluctuation and to verify the dynamic models of two types of boiler.

In analysis, the circulating system is particularly discussed to clarify the difference between both types of boiler. The frequency response of the whole system is obtained by transfer matrix reduction, connecting transfer matrices of subsystems. And the experimental results are obtained from in frequency domain by using pseudo random signal and from step responses by Fourier integral.

Calculated results agree closely with experimental ones, and the followings can be suggested:

(1) Whether the circulating pump is provided or not would give no essential difference in the dynamics of the circulating system, so far as drum level and pressure are concerned, between both types of boiler.

(2) The differences of the dynamics and of the allowance are caused by water holding and metal weight.

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Section Applications (Process Dynamics)

On the optimal temperature control of the multivariable control system "once-through boiler" under fast load changes

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Modern thermal power plants are used more and more to take part in frequency control and in peak power generation. Thereby the permitted speed of the load change is limited by the temperature control of the superheater system. Therefore in this paper especially the temperature control system is considered with regard to its structure and the setting of its controllers. The interconnection of the temperature control, which is itself already a multivariable system, with other parts of the boiler control system is regarded.

The dynamic behaviour of the superheater system of a 530 t/h once-through boiler with a combined oil and gas firing is calculated on the one hand out of the construction data and the operating conditions of the plant, on the other hand by analysing numerous plant measurements. The method for simulating the temperature control system on an analog computer brings high accuracy and needs only a low number of amplifier. Using this simulation method the stability and optimization of the multivariable temperature control system is investigated. As a result proposals are made for an advantageous structure of the control system and for optimal controller settings.

OPTIMUM CONTROL ALGORITHM BY MEANS OF SURPLUS AIR IN FIREBOXES OF STEADY FUEL FIRED STEAM BOILERS

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Summary

In the article two algorithms for optimum burning process are given. One of them coordinates the results of three subsequent measurements of dry flue gases components and the other - of wet flue gases components measured at outlet of the steam boiler.

These measurements are performed for different surplus air amounts in steam boiler fireboxes after stabilization of the burning process.

INVESTIGATION OF THE DIRECT DIGITAL CONTROL OF AN ONE-THROUGH-BOILER

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There are several control algorithms investigated based on minimum of quadrate errors. The algorithms are calculated by means of a digital computer according to a general program. All the calculations are performed in the time domain only.

The investigation is partly done in the laboratory,partly in the power plant. In the laboratory an analogue computer is used as a model of the controlled system, the digital computer as a digital control. In the power plant a digital computer LGP 21 is coupled with the electronic analogue control system ERS.

DIGITAL CONTROL TECHNIQUES FOR POWER PLANT APPLICATIONS

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To meet the expanding needs of power plant control modern day digital techniques have been analyzed. The requirements for power plant control algorithms have been reviewed and a set of linear and nonlinear numerical procedures have been developed.

The difference equation for each algorithm is presented and the transient response plotted. A typical "once-through" feedwater demand controller is simulated with an experimental nonlinear model and transient results are discussed.

It is concluded that digital control applied to power plants can be come a powerful in-the-field design tool to improve the performance and the availability of power plant installations.

CONTRIBUTION OF THE ANALYSIS OF NON-LINENRITIES OF THE GENERAL LAW OF TRAFFIC Q = Cv

by

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F r a n c e

The author tries to present a model of the general law of traffic taking account of the mathematic expectations of speed distribution and concentration of vehicles, correlated according to the relation of the continued traffic capacity to the imposed security spacing /equation 16/.
This law may be adapted to the study of generalized fish-type flows and allows to justify the formation of shock waves. It may also serve in the interpretation and simulation of space-time diagrams in free circulation and in automatic coordination by lights.

SETTING LINKED TRAFFIC SIGNALS TO MINIMISE DELAY

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Two experiments in Glasgow and West London involve the control of traffic signals by central computer with the object of determining how to make the best use of existing road networks. The value of control systems is being assessed in terms of the average journey time of vehicles using the network. Systems based on the use of linked, fixed-time traffic signals have been used in the early part of the experiment and two new methods of setting such signals to minimise delay have been developed.

The Combination method assumes that, in a network controlled by traffic signals the delays on each link are affected only by the settings of the signals at each end of it. A histogram showing the delay to traffic on a link for all the possible offsets of the signals at each end is first obtained. Histograms for parallel and adjacent links are then combined by a form of dynamic programming, optimum signal settings being obtained at each step, until the network has been reduced to a single equivalent link. The method is applicable only to certain types of network but in practice this has not proved to be a serious limitation.

A full-scale trial was carried out in Glasgow, where Combination method settings were compared with those in use on the existing system of linked and isolated vehicle-actuated signals. Average journey times were reduced by 11 per cent during the morning peak, by 3 per cent during the period between peaks and by 20 per cent during the evening peak. It is estimated that the average reduction of 12 per cent in average journey time throughout the working day, if maintained for a full year in Glasgow, would be worth about £600,000 per annum.

An alternative method, TRANSYT, uses hillclimbing techniques to determine optimum fixed-time signal plans. A traffic model is used in which allowance is made for the flow interaction between adjacent road sections, for the dispersion of platoons and for control by signals or priority junctions. Both the signal offsets and the duration of the green times are optimised.

A comparison of TRANSYT and Combination method settings took place in Glasgow in May-June 1966. Average journey times with TRANSYT were lower by about 4 per cent, roughly as predicted, but this difference was not, however, statistically significant. Including this reduction, the TRANSYT results would represent an estimated saving of £750,000 per annum over the existing system.

It was concluded that both techniques produced substantially lower journey times than the existing Glasgow system with its signals set by hand, but the evidence was insufficient to establish any difference between them.

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THE TRAFFIC PLANNING ALGORITHMS OF THE PASSENGER AIRCRAFT AND THEIR OPERATIVE CORRECTION /AUTOMATIC CONTROL OF THE TENDENTIONAL SYSTEM/

The algorythm of the aviation transport network automatic control comprises a block of the aviation passenger transportation demand prognosis, some blocks of the transport network graph and traffic plan calculation and a feed-back block for correction of plans with the change of demand concerning the prognosis. The demand prognosis in carried out on the basis of the probabilistic model which describes the function of the air transportation demand distribution, depending on the transport situation character for the respective pair of towns. This situation is defined by the ticket cost, the time of movement and by the all kinds of transport movement frequency.

Main air communication graph has as its basis the system of the airlines, set during a number of years. This graph is being corrected afterwards.

The traffic-plan means the distribution of the airplanes for the airlines, considering special conditions of the airplanes disposition and pointing the number of flights for each airline. The calculation of the plan is carried out by the solving of the nonlinear programming problem and by the use of iteration method.

Durring the plan calculation automatic correction of the communication graph is being made by denoting the airlines which have small passenger traffic and by adding extra flights for overcrowded lines.

The feed-back block provides rapid plan recalculation if there appears the change of demand concerning the prognosis. The correction of the plan is made on a small region of the graph. The part of the graph to be corrected is pointed on the basis of denoting the airlines having the common passenger flow.

The automatic control algorythms are realised on the high-speed computer and are used to make and correct traffic plans.

THE APPLICATION OF AN OPTIMISATION METHOD TO THE TRANSITION PROBLEM IN HELICOPTERS

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The transition problem may be defined as a change of altitude combined with a change of speed. This usually means decelerating from cruise speed to hover while losing height at a controlled rate or conversly, accelerating while climbing. During such a transition the helicopter changes its characteristics such that any given control law will not give the best performance throughout the flight profile. Optimum laws can be found at each speed during transition and assuming the system is not made adaptive, i.e. continually changing control law, it is necessary to find one law that will give the best performance throughout the flight. An investigation has been made towards finding such a control law.

Since there are two control variables, longitudinal cyclic blade angle and collective blade angle, which can be used to control the two output variables, vertical speed and forward acceleration, several control laws can be found at each speed by varying the weighting function. To initially simplify the study the control variables were separated and optimal control laws were found. With these results, estimates of the required weighting functions for the two-input two-output performance index could more readily be made. Laws were then found for a particular speed and when a satisfactory transient response was obtained laws were found for other speed cases. Each law was used at every speed and the suitability of using any particular law throughout the speed range was considered. From this it was possible to obtain a guide in finding a law which might give satisfactory performance in all cases. All the analysis was performed with a linearised model which necessarily restricts the accuracy of the results, but as a preliminary study the optimisation technique is very useful.

DIGITAL CONTROL FOR AN AIRCRAFT WITH VARIABLE CHARACTERISTICS

D. Bux, G. Schweizer, H. Seelmann

Variable stability aircraft have been developed and investigated within the frame of various research programs. So far, aircraft with variable performance which would have benefits for modern pilot training, have not been designed. In the paper, various possibilities for the realization of the control system for such an aircraft will be discussed. The basic problem is to control the trainer in such a way, that within all manoeuvers, the statevariables of the airplane to be simulated, are achieved. One has to deal with a multiloop complicated control system, which can only be realized with a digital process computer. The algorithms for the on-line solution of the control problems based on modern control methods are explained.

EXPERIMENTS ON A HYDROFOIL TEST CRAFT WITH A HYBRID FOIL SYSTEM AND AN AUTOPILOT

Y. Ohtsu*, T. Fujino*, M. Itoh*, H. Ohno* and K. Uchino**

In the present report the results of experiments on foilborne cruising sea trials of a hydrofoil test craft with a hybrid foil system and an autopilot system is qualitatively described. It is also shown that an analysis of the longitudinal dynamics of the craft will be helpful to the fundamental design of an autopilot system.

Each fore foil of the port and starboard of the test craft has a fully rotating foil at its bottom and the after foil has a flap at its trailing edge. The incidence angle of the rotating foil and the flap angle are controlled by hydraulic servo mechanisms.

The height over the water line and the pitch angle of the hydrofoil craft are taken as controlled variables and an incidence angle and a flap angle as manipulated variables. The longitudinal dynamics of the craft with the hybrid foil system may be treated as a controlled system with mutual interaction, which has two inputs and two outputs. A synthesis of the autopilot system with mutual interaction in the craft dynamics has been studied by using root locus diagrams of the system.

From the results of sea trials in several autopilot modes it has been found that the deviations of the controlled variables from the trim of the craft are considerably suppressed when a rate signal of the controlled variable is fed back, and that the deviations from the set points of the autopilot is more decreased when the position signal is also fed back with the rate signal. Furthermore, from the result of present experiments it may be suggested that, when the position and rate signals of all the controlled variables such as height, pitch angle and roll angle are simultaneously fed back, the deviations of each controlled variable in the craft with the hybrid foil system could be made as small as those in a craft with the fully submerged one.

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THE DYNAMIC CONTROL OF AUTOMOTIVE TRAFFIC AT A FREEWAY ENTRANCE RAMP

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The work presented in this paper concerns the design and analysis of a dynamic control system for metering automotive vehicular traffic onto a high speed urban freeway. The problem treated involves the utilization of an automatic traffic controller that regulates the entrance flow of vehicles to a rate which minimizes the total expected delay experienced by vehicles entering the roadway, subject to the restriction that the entrance flow does not cause a breakdown of flow along the highway. The study is part of the Gulf Freeway Surveillance and Control Project conducted in Houston, Texas, for the United States Bureau of Public Roads, by Texas A and M University, and all experimental results were obtained from this project.*

Two criteria are considered in the mechanics of "ramp metering": One involves the insertion of entering vehicles into gaps, while the second involves metering vehicles into the stream at instants dictated by the margin between observed flow and highway capacity. In either case a stochastic state model is used to study the dynamic behavior of the control system. The state of the system is determined by the number of vehicles in the queue awaiting service in conjunction with the presence or absences of a trapped vehicle on the end of the merge strip. Control is exercised by the release of vehicles (that are stopped and awaiting service) as is indicated by continuous monitoring of highway flow. The basic design parameter in the system is the threshold limit at which the next vehicle is released (provided that the previously released vehicle has completed its merge). In all, several designs were investigated including: a fixed control system, with a predetermined threshold; a programmed control system, in which the threshold is varied as a function of time; and a feedback control system, in which the threshold is varied as a function of the average stream volume. The resultant control systems were or are being implemented and tested on the Gulf Freeway.

* The opinions, findings and conclusions expressed in this publication are those of the author and not necessarily those of the Bureau of Public Roads.

LINEAR DIFFERENTIAL GAMES WITH COMPLETELY OPTIMAL STRATEGIES AND THE SEPARATION PRINCIPLE

Pierre Faurre

Summary

This paper treats the linear differential games with quadratic performance index. The existence of optimal strategies in the case, when an associated Riccati equation has a solution, is proved; it is proved also that the strategies obtained are completely optimal in the sense of fact that the adverse strategy knowledge would involve to use still the same strategy (as without knowledge), called completely optimal.

The direct method used here is extended to the stochastic case where the formalism of Ito stochastic differential equations is applied. It turns out that the principle of control and estimation separation can be extended to the stochastic games.

STOCHASTIC OPTIMAL CONTROL WITH PARTIALLY KNOWN DISTURBANCES

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The stochastic optimal control of linear, discrete scalar system is studied. A method is presented for relaxing the usual assumption that the probability distributions of the disturbances are known.

We regard the additive white Gaussian disturbances to have fixed but unknown parameters. The basic idea is to consider the unknown parameters as random variables whose a priori probability densities are given. Applying Bayesian filtering theory, the problem solution consists of recursion equations for sequentially computing the a posteriori probability densities of these random variables based on measurements. From these a posteriori probability densities estimates can be formed.

To determine the control, the expected value of a quadratic cost functional is used as a criterion function. Applying Bellman's dynamic programming approach, we obtain the exact analytical solution of the feedback control law. This solution serves as standard for evaluating approximate solutions.

AN APPROXIMATE METHOD OF STATE ESTIMATION AND CONTROL
FOR NONLINEAR DYNAMICAL SYSTEMS
UNDER NOISY OBSERVATIONS

by

Yoshifumi Sunahara

The object of this paper is to establish an approximate technique for the state estimation and optimal control of nonlinear dynamical systems with state-independent noise under noisy observations.

Guided by the basic notion of state variable representations in control theory, we describe approximately mathematical models of both the dynamical systems and the observation process by the nonlinear vector stochastic differential equation of Itô-type.

The description is basically divided into two parts.

Firstly, a method of stochastic linearization is demonstrated for the purpose of establishing an approximate approach to solve filtering problems of nonlinear stochastic systems in Markovian framework. Although the most familiar technique is the introduction of Taylor series expansion on a nonlinear function, in this paper, the author will introduce the reader to a method of stochastic linearization which will be shown to play a useful role in the study of state estimation and which will hopefully be of an extensive use to the version of optimal control problems. The principal line of attack is to expand the nonlinear function into a certain linear function with the coefficients which are determined under the least squared error criterion. The linearized function is specified by the coefficients dependent on both the state estimate and the error covariance. Thus, a method is given for the simultaneous treatments of approximate structure of filter dynamics and of running evaluation of the error covariance through the linearized procedure.

Secondly, by using the filter dynamics obtained, an approximate method of optimal control is presented for the quadratic cost functional.

Finally, detailed discussions are given with numerical examples, including comparative discussions on the other filter dynamics.

CONTROL ON STOCHASTIC PROCESSES AND CHECKING

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A.I. Yashin

It is solved a problem of synthesis of an optimal algorithm for checking and control of a discrete stochastic process, with incomplete information. Three types of losses are described:

- for the deflection of the controled process $\{\eta_p\}$ from a given regime $\{\theta_p\}$
- for the control of the process $\{\eta_p\}$
- for the checking of the process $\{\eta_p\}$.

Let the number of cycles of process existence be finite and equal to N. Operations of checking and control, and also incoincidence of coordinates y_n and θ_n, $n=1,2,\ldots,N$, result in total stochastic losses C_Σ. The mean value of C_Σ is minimized by means of choice of a number, and of checking and control moment lay-out, also by a choice of control U_k, $k=1,2,\ldots$ The problem is solved by means of dynamic programming methods.

SYNTHESIS OF CONTINUOUS-TIME STOCHASTIC CONTROL SYSTEMS

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Analytical results in continuous-time stochastic control theory are normally developed for systems whose noise is white, as the Markov assumption is usually needed in the derivation. However, all random processes met in practice involve coloured noise, and such processes must be modelled by white noise processes before the results of stochastic control theory can be applied.

This paper relates continuous-time coloured noise and white noise processes in a convenient state-vector form for the case where the upper frequency of the coloured noise is high. The problem is most interesting when the noise is non-additive, and the paper gives the maximum number of parameters of the coloured noise which are needed to relate the two processes.

Using this relation, the paper shows how some of the modern stochastic control theory can be applied to practical situations. An example of a linear system with a random coefficient is studied, and it is shown how an inferior controller can be designed if the coloured noise is not characterized fully.

CHARACTERISTICS OF STOCHASTIC PURSUIT-EVASION* GAMES

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Several characteristics of stochastic pursuit-evasion games are considered. The outcome of the game as a function of the information set is investigated with respect, in particular, to the role of the stochastic strategies as a bridge between open-loop and closed-loop strategies. The stochastic game is also shown to shed further light on the asymmetric character of the roles of the pursuer and evader. Further, it is pointed out that if the two players have different information sets a nonzero-sum game must be solved.

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INEQUALITIES FOR THE PERFORMANCE OF SUBOPTIMAL UNCERTAIN SYSTEMS

by

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The performance index for a control system depends both upon the selection of a controller and upon uncertain quantities, such as perturbing inputs. To each controller corresponds a function of the uncertain quantities to which is assigned a number by taking, for instance, an expectation. In general it is difficult to find a design giving this number its least value J^*. One suboptimal design method consists in assuming that the uncertain quantities are fixed at typical values and finding a design optimal under this hypothesis. When such a design is evaluated the result is a number $J_0 \geq J^*$. The risk entailed by the simplified design method can be studied in terms of inequalities $J_0 \leq kJ^*$ where k is as small as possible for given assumptions on the structure of the problem. Best values of k are found for a class of open-loop problems with norm type criteria. Depending on the assumptions, these values are $2/\sqrt{3}$, $\sqrt{2}$, 2 or 3. Inequalities for two-stage problems with feedback are also derived.

TWO-ROTOR GYROORBIT THEORY

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The theory of one-rotor gyro orbit is known now which is used on artificial earth satellites to make planes of their orbits. Together with the local vertical measuring element of infrared or any other type the gyro orbit gives possibility to make up current orbital coordinate system on board of an artificial satellite which can be used as a basis coordinate system when the satellite is doing its various tasks required. The scheme of the two-rotor gyro orbit is known which has many advdntages in accuracy, greater gyroscopic memory, manoeuvring, etc.

In the paper on the base of consideration of initial differential equations and composition of noises principal theoretical dependences are given for the process of making up current orbitial coordinate system in normal orientation regime and gyroscopic memory.

The main results of this analysis are the shown transformation of noise frequency spectrum determined by the own drifts of gyroscopes and also more favourable conditions of work in gyroscopic memory regime in comparison with one-rotor gyro orbit.

INVESTIGATION OF MULTIPLEX AUTO-OSCILLATIONS OF SPACECRAFT

E.V.Gaushus

The dynamics of a spacecraft with a pulsed attitude control system is considered. Plane oscillations with constant disturbing moment are investigated. The problem is solved by the method of point transforms and the theory of bifurcation using some theorems proved by the author.

The dynamic system considered is shown to have any multiplex periodic motions (fixed points of a point transform of any multiplicity from 1 to ∞).

The complete problem of the dynamics investigation is solved that includes finding all possible periodic motions, studying their stability and parametric dependence, fitting bifurcation curves, and determining energy consumption by the control system. The energy consumption is shown to be quantized, i.e., the system can be at one of two possible energy levels corresponding to limit cycles of neighbouring multiplicities at fixed parameter values. The dynamic system considered with a multivalent phase plane seems to be the first example of systems which have any multiplex periodic motions and can be fully analysed.

DYNAMIC STUDIES OF PRELIMINARY STABILIZATION SYSTEM OF A GRAVITY-STABILIZED SATELLITE WITH TAKING INTO ACCOUNT TRANSDUCERS CONSTRAINTS AND BENDING OSCILLATIONS OF STABILIZER

V.I. Popov, V.Yu. Rutkovskii

In certain cases the gravitation and stable satellite should be quickly calmed after separation. The calming can be effected by means of a gas-reactive pre-calming system (PCS).

The dynamics of PCS is investigated on a phase plane with the transmitter limitations being considered. The question is considered of using the transmitter limitations in forming non-linear control laws. It is shown that with the coeffecients in the regulation law and the dead time in the system being chosen in a definite way, a substantial ecenomy of working body may be achieved.

Auto-oscillating duties in the PCS are being investigated. To reduce the amplitute of auto-oscillations in the PCS, which has a relay characteristics with a hysteresis loop, it is envisaged to introduce an inherent feedback compensating the dead time of theregulator.

To obtain a gravitation and stable satellite, a stabilizer is being attached to it. After the satellite is separated from the delivery rocket the stabilizer should be opened. The moment of opening the stabilizer is being chosen.

Equations are made of plane curve oscillations of the system satellite-stabilizer, their investigation is made. If only natural damping in the bars of the stabilizer is taken into account, energy practically does not dissipate for an admissible time interval, when artificial damping is introduced in the bars oscillations in the system damp quickly.

Curve oscillations in the system satellite-stabilizer were examined on the digital computer with the work of the PCS being considered. It was shown that when the PCS has a relay characteristic with an insensitivity zone, curve oscillations of the system satellite-stabilizer can be damped during an admissible time interval.

THE DESIGN OF AN 2-AXES-ATTITUDE STABILIZATION SYSTEM FOR SPINNING PAYLOADS

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Scientific Experiments require often payloads which are pointing accurately towards a star or the sun. The hardware of attitude control systems for spinning payloads becomes quite simple, careful dynamic investigations, however, are required.

On the basic of an optimization study with Pontrjagin's method towards a time-optimal control system, a quasi-optimal discrete control system has been designed. Nutation and precession control is treated in detail in the paper. Results of the development and various technical realizations are presented. Problems of the sensors, the signal processing and actuators will be explained. The results of hardware simulation are shown. The system will firstly be launched in 1969.

TURN MANEUVER CONTROL OF A CIRCULAR ORBIT PLANE PROVIDING FOR A SATELLITE PASSAGE THROUGH A GIVEN

Yu.P. Gouskov, S.V. Bunjakin

The problem of sinthesizing the throttle control, which provides a satellite pass over a given point on the earth's surface, is examined using the known decisions of the material point motion equations in the cental field under the effect of force applied binormally to the osculating orbit.

A distinctive feature of the trajectory programming problem being examined in this report is the conjugation of the earth's surface point motion to the powered and unpowered satellite motion provided that the engine bourns minimum time.

A requirement of maintaining the parameters of the initial orbit as well as the given final requirements under the action of perturbations, which take place, necessitates synthesizing a feedback control system. One of the possible circuits of such a system is analised in this report.

On the Synthesis of a Control Moment Gyro

Implemented Spacecraft Attitude Control System

by

E. George Smith*

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The preliminary design of a spacecraft attitude acquisition/reorientation and stabilization controller, implemented by a set of single-degree-of-freedom control moment gyros (CMGs), is described in this paper. For cases of motion-in-the-large, equations governing system motion are highly nonlinear as evidenced by the serious cross-coupling effects. Assuming that a control algorithm should be contrived to permit efficient use of the inherent nonlinearity of the control actuator, (1) an application of the classical variational calculus is made which results in a control law governing the motion of an ideal CMG controller and (2) the method of steepest descents is employed to synthesize a CMG torquer control law which forces a close realization of the ideal CMG motion. Some results of a computer simulation of the total system are presented along with a derivation of the simulation mathematical algorithms.

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*Advisory Engineer

ON THE SYNTHESIS OF SUBOPTIMAL, INERTIA-WHEEL ATTITUDE CONTROL SYSTEMS

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Two techniques are presented for the synthesis of suboptimal systems using motor-driven inertia wheels as the source of torque for three-dimensional attitude control. These techniques approximately minimize the integral of a quadratic function of system error and control effort, and both procedures compensate for nonlinear inter-axis coupling. The techniques developed in this paper are applied to the design of an attitude control system for a typical artificial satellite. The resulting control laws are in feedback form. In a computer simulation, systems designed on the basis of the procedures developed are shown to respond faster and more accurately than those designed by optimization procedures based on linearized approximations of the equations of motion.

GENERAL PROBLEMS OF GUIDANCE THEORY

E.A. Fedosov, A.M. Batkov, V.F. Levitin, V.A. Skrypkin

/MOSCOW/

The only approach to designing of control systems of flying apparatus is suggested. General problems of guidance is discussed. It is seen, that in general, problem of: remote control, self-guidance, autonomic control, guidance of flying apparatuses to mooving and steady targets from mooving and steady platforms, are defined as follows:

a/ The only criterion, stating the quality of work of guidance system, for instance "overflying" of the target by flying apparatus;

b/ The only, unchangable part of the system, kinematic equation of connections between parameters of flying apparatus trajectory and target,

c/ Control elements specific and characteristics of flying apparatus, and as well, lack of full informations in their changes,

d/ The only necessity of dicrease in power looses of flying apparatus, necessery for guidance needs.

Different guidance problems are in general defined by information sources of the target and flying apparatus and especially flying apparatus characteristics.

General features and specific problems of remote control, self-guidance and autonomie guidance systems, are illustrated by an example of linear system of guidance. Optimisation of guidance system problem is discussed. Special solution problems at different information sources and consideration of different power limitations, are analised. Antiaction of the target on guidance system characteristic is studied.

Presented are analisis methods of guidance system with consideration of absence of full information about flying apparatus characteristics.

THE RELEVANCY OF CONTROL THEORY TO EDUCATIONAL ENROLMENT

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The paper is concerned with an important problem of educational planning, the future distribution of students and teachers, and the applicability of control concepts. Some previous attempts at applying control concepts to educational enrolment are briefly described; these attempts utilized such ideas from control theory as, state space, control or decision variables, Pontryagins maximal principle, dynamic programming and dual systems.

Next, attention is focused on the formal similarities between an industrial process and the educational process. It is then shown that despite the formal similarities, many very real problems still exist; the controller is only a "suggester", the dynamics of the process is almost unknown and moreover is non-stationary and the setting up of an objective function, unanimously agreed upon seems to be an almost impossible task. Because of these difficulties, it is seen that a control framework must be augmented by some deep and unfortunately expensive research into the educational process itself.

THE USE OF MULTIACCESS COMPUTERS FOR THE MANAGEMENT AND CONTROL OF PROFESSIONAL LITERATURE

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Multiaccess computers, when operated in an online mode in which users interact in real time with the machine, in dialog fashion, offer new opportunities for effective management and transfer of information contained in the professional literature. Active interest of members of the profession and a certain amount of standardization are essential for effective implementation of a machine-stored information system. The automatic-control field is an excellent area for exploitation of this type of information-transfer system because of the worldwide cohesiveness of its professional membership.

An Experimental Information-Transfer System (Project Intrex) is described. Its purpose is to develop, through analytical and experimental research, a body of data which will be useful in the establishment of specifications of future operational systems. A salient feature of the experimental-system design is that it takes full advantage of the capabilities of the user as a human operator in the man-machine interaction process. The system includes a literature base consisting of a catalog of at least 10^4 documents, a set of storage and retrieval programs for storing the catalog compactly in the multiaccess computer and for retrieving information quickly from the catalog, and a full-text-access system which ensures guaranteed, rapid access to the full text of the cataloged items at remote locations. Experimental results obtained to date are reported.

COMPUTER CONTROL SYSTEM FOR AIR POLLUTION

by T. TAKAMATSU, Y. SAWARAGI
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Y. IKEDA, K. KAWATA and T. MIZOGUCHI

In Japan, public nuisances caused by air pollution have been tremendous problems, and especially in the Osaka district that has many industrial towns, it has become one of the problems which should be immediately solved. Therefore the authority of Osaka Prefecture has installed the telemetering system to quickly grasp the conditions of weather and air pollution at several monitoring stations in the Osaka district. Only this installation, however, is not enough for the prevention of pollution, and the emitted materials from many pollution sources should be so controlled according to some policy that any public nuisance does not occur.

It is the purpose of this work to develop the methodology for establishing this control policy. Future concentrations of air pollution materials are predicted by some mathematical models, and if predicted values of future concentrations are estimated to be over the critical values, the emitted quantities from sources must be so reduced that future concentrations do not be over the critical. In this case, it may be desirable that the total sum of reduction of social and economical activities in the district is minimum, and these control may be accomplished by using electoronic computer with many modern control theories.

This paper is mainly on mathematical model building with transfer phenomena of pollution material in air,and on some results of calculations by using the model.

To calculate the transfer rate in the horizontal direction, steady state distributed parameter models are used, and for each of the small! regions about monitoring stations a pseudo perfect mixing model is applied. The concentration of upper zone of small region mentioned above is calculated based on the transfer in the horizontal direction, and some transfer are carried out between the perfect mixing region and its upper region.

Moreover, since values of many parameters contained in mathematical models vary with time, these values should be always modified by the principle of adaptive control and by comparing calculated values with measured values.

'Dynamically Optimized Fiscal and Monetary Policies for the Control of a National Economy'

by A.R.M. Noton (Canada)

This paper illustrates the application of techniques developed in an engineering discipline to a problem of another discipline, namely the social sciences. Even though mathematical economists are familiar with variational methods there seems no evidence that modern control theory has been applied to derive dynamically optimized control policies for a national economy. A model of eleven state equations embodying several interesting features has therefore been used for such an illustration, Although no serious attempt has been made at this stage to correlate the model to econometric data. The problem (for discrete-time control) is formulated as one in dynamic programming and the iterative computations proceed with the help of expansions using the method of conjugate gradients.

INFORMATION SYSTEMS DESIGN FOR BUSINESS APPLICATIONS

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The process of information system design in the past has received insufficient attention because of the emphasis on selecting from available hardware. However, as in the solution to any problem there are several phases in obtaining a suitable design for an information system and this paper describes the process of arriving at such a design. This process, carried out by a systems analyst with the help of operating personnel and management at all levels can benefit from the experience of control engineers.

There is a strong resemblance between management functions and multiloop control systems. Further the management functions can be shown to include the control aspects which would analogously be done by control logic and feedback in a physical system. Matrix manipulation and partitioning may be used to design better information systems. The techniques of optimization will also be found useful in the selection of strategies and planning by management.

As the capabilities of information systems are explored it will become evident that experience in modeling and simulation will be useful to create management descriptions of the business in a more quantitative fashion. Thus, alternate courses of action may be explored and long-range planning and decision making may be more scientifically investigated.

A Nonminimum Phase Index and its Application to Interacting Multivariable Control Systems

by

Edward J. Davison

A nonminimum phase index is defined for a linear time invariant multivariable system. It is then used to give a measure of the degree of difficulty of stabilizing the system when two or more control systems, each of which controls one output variable of the system, are applied simultaneously to the system. The index is simple to compute and so should be useful in predicting when interaction will occur in large multivariable control systems such as which occur in process control. A numerical example of a distillation column with pressure control and temperature control is included.

ON AN ALGEBRAIC , MULTIDIMENSIONAL

DAMPING CRITERION

EXTENSION OF NASLIN'S CRITERION

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The first part of this work concerns an extension of Naslin's standard polynomials (representing differential operators) frequently used in one variable control design. Standard polynomial matrices are presented and justified. The second part concerns an essential problem in the practical field of multivariable control synthesis. When controllers of classical structure (such as the three terms controller PID) are used, no method is actualy available for matching the controller to the controlled process to improve the dynemical behavior of the over all control system. A practical method is proposed which may solve the stated problem. The method is based on an extension of Naslin's scalar damping criterion to the multidimensional domain. However, many aspects of the extension remain to be studied, to justify the usefulness of the generalized criterion.

USE OF GENERALIZED MOHR CIRCLES FOR MULTIVARIABLE REGULATOR DESIGN

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A design technique is presented for multiple loop, multivariable,linear,proportional regulators. The technique depends on the use of generalized Mohr circles. The Mohr circle construction was first introduced by Otto Mohr in 1882 to show the effects of coordinate axis rotation on stress and strain tensors. The principal object of this paper is to show how similar constructions can be used in the design of multivariable feedback control systems. The familiar complex frequency plane is used, so that a link is established between the technique developed and conventional control system theory.

Two simple design examples are presented. One of these, for liquid level regulation in a three-stage blending tank system, is representative of a class of process control applications.

A TRANSFORMATION METHOD FOR THE ANALYSIS AND THE SYNTHESIS OF MULTIVARIABLE CONTROL SYSTEMS BY DIGITAL COMPUTER

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S U M M A R Y

The analysis and synthesis methods of the control theory presume that the system under test is available in a proper mathematical form. However in general the model of the entire system, which was build up by pure mathematical operation on the base of the physical laws or by measurement with an identification procedure appears in different form. The block-diagram is a very useful form and it is widespread in the practice too. In the paper is described a general procedure to generate the proper mathematical form, which is wanted by the analysis and synthesis methods, on the base of the block-diagram.

In the first part we describe the generating procedure of the state equations. The second part deals with a transformation method to convert the state matrix of a system into a kinematically similar matrix, which has canonical form. In this way is performed the simplification or the reduction of the genuine block-diagram with regard to the original input signals and output variables.

The information which are comprised in the state equations and in a single transfer element existing between one input-output signal pairs in this way are available. The synthesis and analysis methods, based upon the state matrix or on the transfer function connected with an input-output pair are directly applicable.

The entire procedure which is described in the paper, together with some classical methods of the analysis was programmed on a digital computer.

ON-LINE COMPUTER CONTROL USING WEIGHTING FUNCTION MODELS

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This paper describes a method for on-line digital computer control of a multivariable system which is applicable when linearisation about an operating point provides a realistic approximation to the system dynamics. These dynamics are continuously determined to obtain a model of the system in the form of a number of weighting sequences by the application of pseudorandom binary signals superimposed on the system inputs, and a crosscorrelation technique which virtually eliminates estimation errors due to spurious correlations. The model weighting sequences are used in feedforward and feedback controllers which operate independently to remove the effects of observed and unobserved disturbances from the system controlled outputs by means of a novel recursive procedure. Results obtained for a simulated system are presented.

ON SYNTHESIS OF OPTIMAL CONTROL SYSTEMS WITH THE GIVEN RELIABILITY

V.A. Bodner, K.B. Alexeev, R.A. Zakirov

For the class of automatic control systems which have limited energy resources, the criterion of the optimum consists in minimum energy losses with an admissible time of regulation and other indices of control quality. The ensuring of the set reliability takes place at the final stage of designing according to a concrete diagram. This procedure of the synthesis of contemporary control systems may be explained by the absence of a generalized criterion of the optimum, containing in itself the quality indices and reliability of the system.

An attempt is made in the paper to formulate, for the said class of systems, a mode of their synthesis taking into account the requirements for set reliability at the initial stage of designing. According to the given mode the realization of the optimum system is carried out in a condition of its maximum structural reliability. A measure of the latter is the degree of the structural change in the controlling part of the system with the optimum laws of control being realized.

The diagram reliability of the system whose index is the probability of its flawless work, is being ensured simultaneously with the minimization of the quality function.

The basic principles of the mode are illustrated on the examples of control equipment with a different dynamical structure both in the part of the realization of the optimum system with a maximum structural reliability, and in the part of attaining the set probability of its reliable work.

OPTIMAL CONTROL OF A CLASS OF DISCRETE SYSTEMS

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The paper deals with optimal control of processes where the control variables can be varied only at discrete times. This type of problem may be encountered for example in a computer controlled system. One powerful method for solving this kind of control problems is the discrete maximum principle. An elementary proof of the principle is given.

Some computational aspects of the control problem have been discussed. Especially is considered the linear process.

Finally there are given a few examples to demonstrate the method, and to show the influence of sampling frequency upon system performance.

Optimal Control of Nonlinear Discrete Systems

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This paper deals with the problem of finding optimal controls for systems with state constraints described by nonlinear difference equations. It is shown that this optimal control problem can be formulated as a mathematical programming problem. Assumptions are made concerning the convexity of some sets and the theorem of Farkas is used to derive necessary conditions for an optimal solution. Convexity is obtained by considering the linearized problem. If the system equations are linear and the objective function is convex the conditions are necessary and sufficient for a global minimum. Furthermore it turns out that the results obtained represent a discrete maximum principle of the Pontryagin type. The Hamiltonian becomes a maximum at the optimum point and the transversality conditions are the same as for continuous systems.

Konstanty KURMAN /Poland/

CHAIN MODELS AS INERTIALESS OPTIMAL CONTROLLERS OF MULTIDIMENSIONAL PROCESSES

Summary

A new perspective optimization method is presented- the chain model method. When present methods are used the computational efforts of optimization grow at least with the square of the problem dimensionality; using the described method - they grow linearly. The point of the method is to reduce a dynamic problem to a static one and to use in modelling the variational principles of the physics.

For the problem of the static optimization an electrical "energetic model" of Lagrangian function is determined based on the modified Dennis's analogy. The node potentials represent decision variables and Lagrangian coefficients and the power consumption represents the value of Lagrangian function. On the ground of the modified Maxwell's principle of the minimum power consumption equations of the first Kirchhoff's Law represent "relations of optimality".

The model has "self-optimizing feature" which is conserved when constraints and other nonlinearities are respected in a proper way. The complexity of the model is proportional to dimensionality of the problem. Theoretically inertialess model realizes practically Arrow-Hurwicz gradient method. The solving time of a problem is equal to fractions of a second. The existence of solution guarantees a possibility of stable model construction.

The optimal control problem is reduced to the problem of the static optimization if the energetic model having specific chain structure is build. This model can be used as the inertialess optimal controller for a wide class of problems.

ELEMENTS OF INFORMATION CONTROL THEORY

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A.V. Zaporozhets, A.S. Uskov, I.D. Xotchubievsky

It is possible to treat control processes in the cathegories of information theory and statistical physics if a composite system is partitioned into different hierarchical organization levels.

So, for each hierarchy level, some information characteristies of general type control processes are studied. The basis for information characteristics derivation is introduced by the authors, and formed by state resolution levels of the control object upon its studied organization level.

The information characteristies allow to estimate possible working conditions of control system, including dynamics of deterministic and nonstationary processes.

The entropy-statistic stability problem is generalized and necessary conditions, specific for control system, are described. The analogy and connection of the statistic stability with classical Lapounov's stability problem is presented.

Information conditions represent necessary realizability requirements for the control of a given object with given anality.

A problem of bound, optimal the information sens, possibilities of control system is given.

Potentially possible control system intervels are connected with transfer ability of the element and control system. Specific features of the transfer ability notion, connected with control system peculiarities, are shown. The basic equations for design of transfer ability are given.

In the paper the conditions of basic control and regulation regimes are studied, including control object state stabilization, reproduction of necessary states and information conditions of invariance /absolute, with the accuracy less than /. General entropy balance equations, pertaining the basic control regimes, are obtained. General anylogy between problems in statistic phisics and information control process in chosen. Design examples of the control systems, using proposed methods, are given.

MONTE CARLO TECHNIQUES FOR PREDICTION AND FILTERING OF NONLINEAR STOCHASTIC PROCESSES

by J.E. Handschin (Switzerland), Centre for Computing and Automation, Imperial College of Science and Technology, University of London, London, S.W. 7. (U.K.)

Monte Carlo techniques are introduced to derive numerical methods for both the nonlinear prediction and the filtering problems. Nonlinear, k-stage dynamical systems are simulated and the data used to estimate the relevant parameters of the probability density functions describing the state of the system. Variance reduction techniques are developed to improve the efficiency of the sampling procedures. The Antithetic Variate method and a new two stage Control Variate Method are developed for the nonlinear prediction problem. The Bayesian approach is adopted for the filtering problem. The combination of nonlinear approximate filter equations with sampling techniques results in a new Control Variate method for estimating the conditional mean. Simple, but illustrative, examples are included to show the applicability of the various sampling procedures.

A.G. Ferraté, L. Puigjaner, J. Agulló

INTRODUCTION TO MULTICHANNEL STOCHASTIC COMPUTATION AND CONTROL

The field of stochastic computation, which applies probability as an analog quantity is very promising, and although slightly developed up to now, its intermediate properties between analog and digital computation suggest interesting applications in the domain of process control.

The concept of clocked random-pulse codification of variables is introduced and the analysis of precision is discussed. Probability cannot be measured directly and statistical methods must be applied to determine, by average, pulse-rate value. The dynamic performance of several types of averagers is compared, finally determining the relationship between sample-size, clock-frequency and band-pass.

The generation of stochastic series with specified pulse-rate probability, needs sampled digital or analog noise of rectangular probability density function. The methods to produce such noise from random or pseudo random binary trains are also considered.

To increase the dynamic range of the variables, the authors propose a generalized stochastic codification introducing the concept of mathematical expectation through the use of logarithmically weighted probabilities. The resulting random floating point stochastic codification has very useful and interesting implications.

Normal operators have been revised in order to cope with the requirements of the new multichannel stochastic codification.

For function generation, a peculiar method using noise sources of specified cumulative probability function is presented, and the obtention of such noises is explained.

CORRECTNESS,REGULARIZATION AND THE MINIMAL COMPLEXITY PRINCIPLE IN STATISTICAL DYNAMICS OF AUTOMATIC CONTROL

V.V. Solodovnikov, V.L. Lensky

The solution of the optimization problems in statistical dynamics of control systems results in a system of integral equations, which are incorrect in A.H. Tikhonov sens. Therefore a computer solution of the problems may involve excessive errors, thus the optimal systems appear to be unrealizable.

Incorect, in the above mentioned sense, is also the well known integral equatrion which is the base for statistical methods of identification.

It is expedient to use, for some problems the Tikhonov's methods of regularization to obtain stable algorithms for statistical dynamics problems solution.

It is shown that when choosing corresponding regularized functional of the sorte, the approach to the synthesis problem solutions allows to obtain non only the correct algorithms, but the systems of minimal complexity as well.

The notion and the principles of minimal complexity are formulated.

The application of the complexity principles is ilustated, using several examples. As a particular example serves the synthesis of a nonlinear discrete with finite memory.

COMPUTATION OF OPTIMUM CONTROL FOR A ROBOT IN A PARTIALLY UNKNOWN ENVIRONMENT

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The optimization of systems in which stochastic effects are present has been studied extensively by a number of researchers. An extremely general formulation of these problems has been called by Meier _the combined optimum control and estimation problem_; solution to this problem has been formulated using dynamic programming. Even though several theoretical papers have been written on this subject, there have been very few examples worked out for any cases but the linear gaussian problem.

This paper first describes the application of the dynamic programming solution to the problem of optimally controlling a robot, equipped with sensors, that is operating in an unknown environment. A methodology is presented for formulating a class of stochastic control problems in which there are informational variables that specify the degree of knowledge about the physical state of the system as well as the physical variables of the type encountered in most control applications. These problems are present in a number of areas; the robot example discussed here is related to the general problem of unmanned exploration of a hostile, inaccessible environment; but another formulation of this type has been developed for mission reliability problems. The detailed calculations required to implement this approach are also described. Dynamic programming is shown to be feasible for handling system equations, performance criteria, and constraints that simultaneously involve physical variables and informational variables. The relationships of concepts from system theory such as _dual control_ and _value of information_ to the combined optimum control and estimation problem are also demonstrated.

In the robot problem computational complexity increases exponentially with the number of physical and informational state variables. Thus, many problems of interest are too unwieldy to solve rigorously on present-day computers. In order to attack these problems, a heuristic method based on the optimization algorithm has been devised. It is thus possible in this paper to analyze the relation between the heuristic methods and optimization approaches for a concrete example. The results of heuristic methods are also compared with the performance of humans in some representative cases.

STATISTICAL PROBLEMS OF INFORMATION FLOW
IN LARGE-SCALE CONTROL SYSTEMS

by

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Some new concepts concerning a statistical approach to the information systems theory are presented. The information systems are considered as sub-systems of large-scale control systems. Their organization may be characterized by a spatial structure, a functional structure and a set of operational rules. The measure of the information value (Eq. (1)) based on the semi-ordered linear space idea is proposed which is a generalization of the measure given by A. A. Kharkevitsh. Some more important properties of the stochastic processes of the Markov type, suitable for analysing the phenomena occuring in the information systems, are also considered. The general equation describing the statistical properties of the processes has been derived (Eq. (14)). A method of getting approximate solutions of the equation is also mentioned. The necessary condition for the stochastic stability of the system is given by Eq. (17a).

ON ONE SYSTEM AUTOMATIC CONTROL OF MICROCIRCUITS MANUFACTURING PROCESSES

V.M. Glushkov. V.P. Derkach, G.T. Makarov

Shown are the main features of different technological ways to scheme construction .... from process automatisation point of view.

It is shown that one of the most promising is a "elion" technology.

With the help of electrinic and ionic bundles were prepared transits p - n, micro-welding, unification of microschemes components, polimierisation, division of light-flying connections with local arising of chemical elements target, hermetization, development of photo-resisting layers, foil powdering, were made high tension patterns, were measured and controlled technological process parameters and products, was defined chemical composition - were made many important operations necessary when microschemes are formed.

Conditions of "elion" process flow, which assures high scheme parameters efficiency, great compatness of element composition, some simplification of control task etc, is analyzed.

"Elion" technique represents an example of such new technique, which would be impossible without cybernetics.

Described are difficulties in solution of development of closed control systems which could be able to automatize in full prepared microschemes.

Shown are question examples which must be solved in order to overcame those difficulties. Prepared are conditions for open electronicbundle control system installations for material processing.

Characteristic of worked out in Cybernetic Institute of Science Academy of Ukrain S.S.R. digital computor, is given.

This computor is prepared for "elion" control of microschemes process preparation, including its algorithmic, structural construction and of other features.

Shown are examples of some programmes processing.

A MICRO PATTERN POSITIONING SYSTEM

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The micro-pattern positioning system is necessary for automatic assembling of transistors and integrated circuits. This paper describes about the micro-pattern positioning system developed for application to automatic wire bonding of transistor pellets.

In this system the detection of patterns is accomplished by the special photoelectric microscope with the optical system containing L-type slits, photomultipliers and differential amplifier circuits. When the pattern with dimensions of several hundred microns is fed in X or Y direction, the photoelectric microscope generates an output pulse at the precise position depending upon the optical pattern. The table on which the transistor pellets are placed is driven in X and Y directions by means of micrometer screws, quick-feed mechanisms and stepping motors. The control circuits consisting of counters and logic circuits control the sequence of operation and positioning.

The first step of positioning is quick feed in Y direction. Then it is switched to fine feed by stepping motor at the position of optical mark. The output pulse of photoelectric microscope in Y-motion lets the counter start to count the stepping motor driving pulses. The Y-motion is stopped at the position in accordance with setting of counter. Then the X-axis fine feed starts. The output pulse of photoelectric microscope in X-motion stops the table.

The experiments concerning the effects of pellet position, adjustment of slits, pellet type, illumination and rotational displacement of pellet have been done. The experimental results indicate the accuracy of positioning is within $\pm 5\mu$.

INVESTIGATION OF A RECTIFIER REGULATING CIRCUIT AS A SAMPLED DATA SYSTEM

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1. General

1.1. Summary

Typical characteristics of rectifiers are discontinuous. If one device is ignited, then the process can only be altered again when the following device is ignited. Investigations into its transient conditions with the normal continuous methods, which use the mean value and modifications to voltage waveform, tend to give inexact results.

Corresponding to the descontinuous mode of the function of the rectifier, the circuit shows substantial similiarities to a sampled data system. However there are two basic differences from the normal linear sampled data system. On the one hand the sampling function is not composed of rectangular blocks, but of sinusoidal sections, and on the other, the sampling period is not constant when the ignition angle is altered.

The switching process of a rectifier is investigated as a sampled data system in reference [1], where it is shown that the parts of a sine wave can be absorbed relatively easily into the sampling function. The behaviour of a rectifier, as the ignition angle changes is determined in this paper. If the investigation is limited to small changes in the ignition angle, then it is possible, as will be shown later in the text, again using constant sampling periods, to determine the stability analysis for a rectifier regulating circuit just as for a normal sampling system.

In the following section 1.2. the well known voltage and current conditions for a rectifier are described and it is shown how the commutation can be approximated.

The behaviour of the rectifier is investigated in section 2 for small changes in firing angle, with special emphasis on the determination of the equivalent circuit diagram and the separate transfer functions.

Before the regulating circuit can be investigated in section 3, the conditions in the gate control circuit must be determined (section 3.1.).

Finally, as an example, the results on a separately excited d. c. motor with rectifier supply and current control are quoted in section 3.5.

HIGH-SPEED CONTROL SYSTEMS WITH FREQUENCY SENSORS

Ye.K. Krug, Ye.A. Legovich

Quick action control systems, where input signals are signals from frequency pickups, have several peculiarities: time of measurement is of course of importance, which can be combined with other time characteristics of the system; frequency signal permits using of analogue and digital methods of measurement and processing; structures constructed on analog technic have limited accuracy connected with static and dynamic faults; presence of sampling when using digital methods of construction limits accuracy of digital apliances of control. Shown are results of accuracy analysis of correcting actions in different types, depending on control system construction. Sugestions are made for construction of systems of different control algorithmes and frequency signal characteristics.

These suggestions are based on possibility appreciation of given control algorithm accurancy /considering necessity of obtaining quick action/ and complication in system realisation by apparatures.

OPTIMUM CALIBRATION OF INERTIAL COMPONENTS

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The calibration of inertial instruments in component, system, and vehicle level tests is shown to be amenable to modern statistical filtering techniques provided adequate models of the processes involved can be found together with some method of solving the immense computation problems. The general form of any calibration system using statistical filtering is given together with techniques for simplifying the computational problem. In one application gyro test table data is processed by a filter and the results compared with a Fourier series analysis. In a second application the design, implementation, and test experience is given for a unique calibration filter used to align and calibrate the Apollo Guidance Navigation and Control System inertial platform while it is in a launch vehicle that is subjected to wind induced sway.

THE DEMELOPMENT OF DYNAMIC COLOR CONTROL ON A PAPER MACHINE

H. Chao
W. Wickstrom

This paper discusses the theoretical and practical aspects of on-line color control that is used successfully on a paper machine at Consolidated Papers, Inc. The contral design schemes for digital controllers are given. Simulation and actual process results are also reported.

THE DESIGN OF A HEADBOX CONTROL SYSTEM PART I ANALYTICAL CONSIDERATION

J.K. Lee, I.B. Sanbourn, H. Chao, J. G. Bollinger, H.L. Harrison

The synthesis of a multiloop control system for a paper machine headbox is considered. An overall control algorithm is chosen on the basis of steady state considerations. Controller gains, etc. are chosen on the basis of system of transient response using a specially modified root contours procedure. The controller parameters designed were verified on actual process.

A MATHEMATICAL MODEL FOR THE OPERATION AND CONTROL OF A BEET SUGAR PLANT

R.M. Withers, R.J. Bass, M.F. Branch

The paper describes the establishment of a practical mathematical model as a basis for prediction of the best operating conditions for maximum profitability in a beet sugar factory. The development of the model is traced from its origin as purely theoretical equations to its present form as a computer programme of operations which accurately represent the process and which are continually up-dated using both ON- and OFF-line data from the factory.

There is reference both to the hardware and software used in data collection, transmission and reduction.

The non-linear techniques used to optimize the model for maximum profit are discussed with particular reference to the constraints which have to be imposed due to practical plant limitations.

Finally the results of the data collection, housekeeping and optimiser programmes are presented to form an integrated computer control system.

MULTILEVEL OPTIMIZATION AND DYNAMIC COORDINATION OF MASS FLOWS IN A BEET SUGAR PLANT

by

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Summary

Changes of the beets quality, inaccuracy of the dosage of energy and materials streams, sudden oscillations of the mass flows, these are the main factors which cause the losses in the sugar production. To minimize these losses an optimizing control, structured as a multilayer system, is proposed.

The first layer consists of stabilizing control. The set points of the controllers are determined by local static optimizers. The losses in the whole technological line are minimized by the global static optimizer which coordinates the work of the local optimizers. The desired production rate is presented as a solution to a dynamic optimization problem - the scheduling problem.

If a temporary limitation of the desired production rate is caused by any reason, then a mass flows coordination system is called upon to control flow rates in different parts of the technological line, to minimize the loss. When the limitation is over, the coordination system brings the line to the previous optimal steady state leaves it to the static optimizers.

IMPLEMENTATION OF COMPUTER CONTROL OF A CEMENT ROTARY KILN THROUGH DATA ANALYSIS

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To implement a computer control of a cement rotary kiln we have first to develop a program which will keep the kiln in a stationary running condition. Usually kilns are quite noisy and they have their own laws of behavior. Thus what we can expect is to keep them in a state where they will be willing to behave in a desirable fashion rather than to force them to a prescribed behavior.

To realize this we have to know the details of characteristics of a kiln and we have done extensive data analysis of running records. Spectral analyses of the records were tried and the result suggested to what frequency range we should pay our attention. The cross-spectral method was found to be insufficient for the present purpose and a control program was developed on a qualitative model of the kiln behavior. The program was found to be fairly successful.

Later a general model for the analysis of feedback systems was introduced and applied to the analysis of our kiln data. It gave a description of mutual interrelations of various measurements and the noise characteristics within the kiln and made it clear why the program worked successfully.

In the paper, these experiences are described in detail.

MODELLING OF A PYRITE SMELTING PROCESS

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A complex gas atmosphere results, when sulphur is extracted from fine-grained pyrite by the flash smelting method. The process is at present controlled by a combination of standard analogue devices. The mathematical model of the smelting process is based on the thermodynamic equilibrium of the gas phase which is described by a set of algebraic equations. After unsuccesful trials with the Newton-Raphson and steepest descent methods this was solved by Rosenbrock's method. Subsequently, the heat balance and the relationship between the compositions of the matte and gas were added to the model. An on-line computer is required for the control of the process using this model, for maximal recovery of pure product.

A GENERALIZED SYNTHESIS OF LINEAR MULTIVARIABLE SYSTEMS

M.V. Meerov, R.T. Yanushevsky

In a solution of the synthesis problem of multiconnected control systems, the choice of its rational structure is of utmost importance. It is established in numerous papers that, in a general case for the multiconnected systems, the autonomy does not appear to be a necessary characteristic, and the tendency to achieve autonomy is often unjustified. In this paper the choice of the structure of a linear multiconnected system is made by solving a minimization problem of an integral square functional of quality, depending on difference of the given, controled and steering signals, upon multiconnected object equations /either with its weighting or transfer matrix function given/ with orbitrary initial conditions, considering disturbances affecting the object. The discussed problem is directly linked with optimal filtration, analitical construction and other problems, but it is distinguished by a general formulation: arbitrary initial object coordinate conditions, subject to the reproduction and disturbances applied to the object. Similarly to the synthosis problem the given problem consists in building a system which acts in a maximum way against distuebances applied to the object /the studied cases are when disturbances could be measured and when they cannot be measured directly/, with effectiveness depending on expression of underintegral quality functional. The problem is solved for the complex area; optimal system structure is discussed. The expressions for transfer matrix functions of synthesized system are brought, the influence of quality functional coefficients upon the system characteristic is examined. The relation of to the structures, beeing stable at unlimited increase of amplification is established. For multiconnected objects having symmetry inside a group, a decomposition method is proposed, which allows to exchange the starting problem for a solution of a number of simpler optimal problems.

THE REDUCTION OF COMPLEXITY OF LINEAR, TIME INVARIANT DYNAMICAL SYSTEMS

D. Mitra

Given a linear time-invariant dynamical system X with n state variables, the problem is the analytical synthesis of a similar system X_r with (n-m) state variables, whose linear outputs are, in a defined sense, good approximations of those of X.

Two principal cases of inputs are considered - (i) weighted impulses and (ii) white Gaussian noise. The corresponding error functionals adopted are (i) $E = \int_0^T \underset{\sim}{e}^t Q' \underset{\sim}{e}\, dt$ and for (ii) M[E], the mathematical expectation of E. The error vector $\underset{\sim}{e}$ is the difference of the outputs of X and X_r; Q' is a positive-definite matrix. Among other variations for (i) the error functional $E = \int_0 f(t)\, \underset{\sim}{e}^t Q' \underset{\sim}{e}\, dt$ where f(t) is any Laplace transformable function, is also considered.

The Gramian matrix W(T) is fundamental to the analysis. It is shown that certain algebraic of differential equations may be solved to yield W(T).

Reduction processes are shown to contain in general two stages

$$\begin{array}{ccccc} \text{Controllable} & \text{Approximate} & \text{Uncontrollable} & \text{Strict} & \text{Reduced} \\ \text{System X} & \xrightarrow{\text{Reduction}} & \text{System, } \hat{X} & \xrightarrow{\text{Reduction}} & \text{System, } X_r \end{array}$$

The strict reduction process involves well-known ideas on the decomposition of state spaces.

The controllable subspace of $\hat{X}$ is of dimension (n-m). The error vector in the approximate reduction process comprises 'tracking' and 'projection' components. Only projections along subspaces invariant under the system's dynamical matrix imply a tracking error identically equal to zero. The method for obtaining the optimal projection along invariant subspaces is obtained.

THE APPLICATION OF NON-INTERACTING CONTROL THEORY TO A CONTINUOUS MULTIVARIATE SYSTEM

by J. A. Planchard and V. J. Law

Numerous empirical methods for the design of controller parameters have been developed in the past and have gained acceptance through widespread usage. However when these methods, which were developed for single loop control systems, are applied to highly coupled multivariable systems, unsatisfactory system performance frequently results.

Within the past ten years, a great deal of multivariable control theory has been developed. Much of this theory has been concerned with one particular aspect of multivariable control, namely non-interacting control. Despite the large body of theory available its practical application has received little attention in the process control field.

The object of this work was to physically implement non-interacting control of a multivariable system whose mathematical model included non-linearities, time delay, and greater than first order equations. Such a system consisted of three stirred tanks in series, to which were fed two streams at different fixed temperature. The output variables of interest were the temperature and exit flow rate of the third tank.

The non-interacting design methods of applicability to this particular plant were then utilized to obtain a number of control systems. Since almost all these methods are based upon linear, time invariant plants without time delay, it was first necessary to cast the model of this plant into that form. Digital computer simulations of the control systems were made to obtain a preliminary evaluation of these systems. The effects of the non-linear equations and time delay on the non-interacting controller performance were obtained in addition to the effect of certain parameters particular to each controller design. A conventional two loop feedback control system was also designed for comparative purposes.

Three representative control systems were then physically implemented utilizing an Electronics Associated TR-48 analog computer for on-line control.

This study showed that reasonably good non-interacting control may be obtained despite process non-linearities, pure time delay and inaccurate model description. Those methods which physically place the controller in that part of the control loop just preceding the plant were definitely superior to those methods in which the controller is placed in the feedback loop. Finally, all non-interacting control systems studied were much superior to a double loop conventional feedback system.

SUGGESTIONS FOR THE DESIGN OF SIMPLE NETWORKS AND ELEMENTS TO COMPENSATE THE INTERACTION IN LINEAR TWO-VARIABLE CONTROL SYSTEMS AND A METHOD FOR FINDING OPTIMAL SETTINGS IN THE PLANT

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It is shown that in the most two-variable control systems better results can be obtained by partial non-interacting control - i.e. with only one additional connection in the control system - than by a total non-interacting control - with two cross-connections in the control system. Basic rules are derived for an expedient layout of partial and inexact non-interacting controls, which are relatively simple to realize and the effect of which greatly improves the behaviour of the interacting system. It is shown that good results can be obtained with only one non-interacting element, out of three proposed simple basic elements.

A method for finding optimal controller settings for a non-interacting two-variable control system is also presented.

ON THE OPTIMAL IMPLEMENTATION OF MULTIVARIABLE DISCRETE LINEAR SYSTEMS

E. Biondi - L. Divieti - C. Roveda - R. Schmid (o)

Abstract - This paper deals with the problem of the optimal implementation of multivariable discrete linear compensators. The objective function, which must be minimized, is a linear combination of the number of delay elements required and the mean square round-off errors on the compensator outputs. In this way, both economy and accuracy will be warrented. Considering the parallel method of synthesis and making use of four basic structures, the optimization problem is approached in terms of graph theory, and corresponds to the determination of the optimal arborescence in a particular acyclic graph. This optimization problem is finally solved via Dynamic Programming.

(o) The authors are with Istituto di Elettrotecnica ed Elettronica del Politecnico di Milano, Milano, Italy.

SENSITIVITY SYNTHESIS OF OPTIMAL CONTROL
UNDER CHANGES OF SYSTEM ORDER

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The object of this paper is to introduce a practical aspect into the present theory of optimal control to bridge the gap between the theory and its applications; the concept of λ-sensitivity is introduced in the synthesis of optimal control when the system to be controlled is subjected to changes of system order.

Firstly, the concept of the λ-combined system is developed, which consists of both the model of a physical system and its λ-sensitivity equations.

Secondly, the controllability of the λ-combined system is discussed. The possibility of compensating the undesirable effects caused by the changes of system order depends entirely on the controllability of the λ-combined system.

Finally, a new method of the sensitivity synthesis of optimal control is developed in the minimum energy problem with terminal constraints from the viewpoint of making the terminal constraints more rigid against the changes of system order. An illustrative example is given to show the advantage of the sensitivity synthesis method over the conventional one.

Andrzej WIERZBICKI /Poland/

UNIFIED APPROACH TO THE SENSITIVITY ANALYSIS OF OPTIMAL CONTROL SYSTEMS

Summary

The paper presents an unified approach to the sensitivity analysis of optimal control systems, which makes possible to compare effectively various structures of those systems. The ideal sensitivity coefficient of an optimal control problem, introduced by Dorato and applied by others, is independent of the structure of the optimal control system. New notions of sensitivity measure and local insensitivity or full sensitivity of an optimal control system with a given structure /open-loop, closed-loop or other/ are therefore introduced in the paper. Local sensitivity coefficients are discussed and variational methods, which help to determine these coefficients, are presented; these methods are based on the second variation of the performance functional. Global sensitivity indexes are also presented. Methods of numerical calculations of sensitivity measure, which are necessary in a general case, are shortly discussed. The paper is illustrated by results obtained in sensitivity analyses of several examples.

A NEW SOLUTION TO THE PROBLEM OF A CONTROL SYSTEM ANALITICAL DESIGN

by A.A. Krasovsky

/M o s c o v /

Synthesis methods for optimum control of linear and nonlinear plants with constraints upon control magnitude as well as on some functions of state variables /those having sense of input signals for actuators in optimal system are presented/.

If linear plant is given

$$\dot{x}_i + \sum_{k=1}^{n} a_{ik}(t) x_k = u_i \ ,$$

then the optimal control, that minimises the functional:

$$I = \int_{t_1}^{t_2} \sum_{i,k=1}^{n} \beta_{ik} x_i x_k \, dt + \sum_{i,k=1}^{n} \gamma_{ik}(t_2) x_i(t_2) x_k(t_2)$$

where

$\sum_{i,k=1}^{n} \beta_{ik}(t) x_i x_k$ - given nonnegative quadratic form

$\gamma_{ik}(t)$ - coefficients, which represent particular solutions to the system of linear equations.

$$\dot{\gamma}_{ik} = \sum_{p=1}^{n} \left(\gamma_{ip} a_{pk} + \gamma_{pk} a_{pi} \right) - \beta_{ik} \ ; \qquad (i,k = 1,2,\dots,n) \qquad \text{I}$$

in the class of controls satisfying the constraints.

$$\int_{t_1}^{t_2} |u_i|^p dt \le c_i \ ; \quad \int_{t_1}^{t_2} \Big| \sum_{k=1}^{n} \gamma_{ik} x_k \Big|^q dt \le \eta_i \ ; \qquad \frac{1}{p} + \frac{1}{q} = 1 \ , \quad p \geq 1$$

apper to be a function of following type:

$$u_i = k_i \left(\sum_{k=1}^{n} \gamma_{ik} x_k \right)^{q-1} \ ; \qquad \operatorname{Sign} u_i = \operatorname{Sign} \sum_{k=1}^{n} \gamma_{ik} x_k$$

Special analytic method for solving the equations for optimal coefficients /I/ on analog and digital computers has been developped.
The method is based on computation of integral square estimation of weighting function of the plant with "frozen" coefficients and on the use of "iterative" method for nonstationary plants or functionals.
If nonlinear plant is given

$$\dot{x}_i + F_i(x_1, x_2, \dots, x_n) = u_i$$

and if there exists a Lapunov function

$$V(x_1, \dots, x_n)$$

which derivative $\dot{V}$

along the trajectories of uncontrolled plant / $U_i = 0$ / is equal to the function $-W/x_1, \dots\dots\dots x_n/$, then the optimal control in class of controls satysfying to constraint

$$\int_{t_1}^{t_2} |U_i|^p dt = C_i \; ; \quad \int_{t_1}^{t_2} \left| \frac{\partial V}{\partial x_i} \right|^q dt = \eta_i \; ; \quad \frac{1}{p} + \frac{1}{q} = 1 \; , \quad p > 1$$

being optimal in the sense of the functional

$$I = \int_{t_1}^{t_2} W(x_1, \dots, x_n)\,dt + V[x_1(t_2), \dots, x_n(t_2)]$$

appears to be:

$$U_i = \pm K_i \left(\frac{\partial V}{\partial x_i} \right)^{q-1} ; \quad \operatorname{Sign} U_i = \operatorname{Sign} \frac{\partial V}{\partial x_i}$$

For passive, specially conservative, plants instead of the function V, the first integral of uncontrolled plant equations can be used - energy integral or its functions.

Examples are given for practical application of discussed methods.

Obtained linear optimal controls allow for unlimited increase of coefficients of canal K_1 without stability looses. Optimal relay control assures invariance with respect to perturbations of limited amplitude.

LINEAR AND NONLINEAR SOLUTIONS FOR THE LETOV-KALMAN'S OPTIMUM SYNTHESIS PROBLEMS WITH APPLICATIONS TO LINEAR PLANTS

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Summary

In the first part of the paper an algorithm for synthesis of time-optimal control law for linear plants with time-varying or constant parameters is proposed. To the synthesis purposes, the state space, considered as a space of plant initial states, is decomposed into manifolds corresponding to a number of switchings. To determine switching instants related to the manifolds, some transcedental equations are developed, their solutions being constrained to satisfy certain conditions. After the latter have been verified, a control law is determined as a nonlinear characteristic, which is adjustable to the initial state with aid of data computed by a separated digital device. The data computation algorithm is represented by a flow-diagram. The nonlinear characteristic for constant plants is given in an analytic form resulting from the known properties of the adjoint equation systems.

In the second part, an optimal nonlinear control law synthesis procedure for integral convex performance indexes is presented. As previously, the adjoint systems properties are utilized. A problem of equivalence of various ways to describe the optimal system and, in particular, the optimal control, is considered. One shows a relation between the adjoint system of differential equations and the Riccati matrix differential equation, as well as a possibility to express a solution to the latter as a function of a solution to the former.

SINGULAR PERTURBATION METHOD FOR NEAR OPTIMUM DESIGN OF HIGH-ORDER NONLINEAR SYSTEMS

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This paper extends the singular perturbation method proposed in an earlier paper by the same authors. For a class of nonlinear systems a sufficient condition is given under which the optimal control is continuous and differentiable with respect to perturbations which change the order of the system ("singular perturbations"). Then a low-order near optimum design for high-order systems is developed. The dimensionality 2(n+m) of the boundary value problem is reduced to 2n, while the performance achieved is close to optimum. Example of the near-optimum design for a fifth order nonlinear plant is included.

*P. Kokotović is on leave from Pupin Research Institute, Belgrade, Yugoslavia

TIME-OPTIMAL CONTROL LAWS FOR NONLINEAR SECOND ORDER PROCESS

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This paper considers time optimal control laws for plants described by $\ddot{\varphi} + f(\dot{\varphi}) + \sin\varphi = u$, $|u| \leq K$. Only partial solutions to this problem have yet been reported. The main contribution of this paper appears to be twofold. Firstly, it presents a generalization of known results in so far as three different damping laws $f(\dot{\varphi})$ and <u>all</u> possible magnitudes K of the control constraint are taken into account. Secondly, in the present case the right hand boundary conditions to be used are $(\varphi(T) = \pm 2\pi n, \dot{\varphi}(T) = 0)$, i. e. the stable equilibrium point of the system.

Pontryagin's Maximum Principle is used for solving the optimization problem. Complete analytical solutions to the posed problem cannot be attained. Thus, possible switching curves are found by way of integrating the canonical system in backwards time. The construction of the field of isochrones provides a means to determine the unique control law $u(\varphi,\dot{\varphi})$ which is characterized in the state plane by true switching curves and indifference curves. Furthermore, the results show that optimization of the system with respect to the exact nonlinear equations has certain advantages over the optimization of a linearized model.

AN APPROXIMATION TECHNIQUE FOR SINGULAR CONTROL PROBLEMS

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A method is presented which permits the solution of singular control problems by approximating the non-normal system with a normal system. It is shown that the approximation can be made arbitrarily accurate. The optimal control of the approximate system is then determined and applied to the actual system. Bounds are obtained on the errors in boundary conditions and the degree of sub-optimality brought about by the technique. The method is valid for minimum time and minimum fuel problems with linear, constant plants. Examples are presented.

A PARAMETER-ADAPTIVE CONTROL TECHNIQUE

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Control of linear stochastic systems with unknown parameters is accomplished by means of an approximate solution of the associated functional equation of dynamic programming. The resulting control signals are linear functions of state estimates with feedback gains depending explicitly upon the parameter identification procedure.

DESIGNING MODEL-ADAPTIVE CONTROL SYSTEMS USING THE METHOD OF LIAPUNOV AND THE INVERSE DESCRIBING FUNCTION METHOD.

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This paper deals with two methods for designing model-adaptive control systems:

1. the second method of Liapunov
2. an inverse describing function method.

The design includes the realisation of a nonlinear adaptive controller, such that the response of the system equals a desired response to a deterministic signal (i.e. model response), independently of parameter variations in the system.
Using these two methods guarantees the stability of the adaptive system. By means of the method of Liapunov an adaptive controller is made, which is usually much more complex than the controller made by using the inverse describing function method but in some cases, it can be simplified. In both cases the result is a controller of which the phase and the gain can be adjusted independently of each other. These two controllers have been tested and compared with each other in several model-adaptive systems.

NONLINEAR FILTERING AND LEAST SQUARES-EXTENSIONS AND APPLICATIONS OF THE QUASILINEARIZATION THEORY

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The quasilinearization approach to nonlinear least squares of Bellman et al is extended to include disturbances entering the system and performance index nonlinearly and nonquadratically. For certain conditions, a non-zero estimate is obtained for the disturbance. Integral constraints can be placed on the disturbance. The formulation includes the least squares counterpart of the statistical estimation problem for "colored" noise and the system with "randomly" varying parameter.

The adaptive control problem is formulated as two optimization problems. These are solved simultaneously using the sequential procedure of the quasilinearization method. The method is general and can include most a priori knowledge about the parameter variations and disturbances acting on the system. There is no adverse interaction between the parameter estimation and parameter adjustment procedures. Results are presented for a simple example.

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Finding the Adaptive Feedforward Function of Controller Parameters by Digital Computer.

In case some of the parameters of a process depend on certain state - or input variables, you can improve the control of the process by introducing adaptive feedforward control of the controller parameters. To do so it is necessary to know the function between the measureable state - or input variables and the controller parameters which are optimal with respect to a chosen criterium. This function is calculated by means of a digital computer. The normal operation of the plant is disturbed as little as possible.

For every operation point a modell plant is calculated by one of two identification methods, which don't need any information about the structure of the plant. The optimization of the controller parameters with respect to the integral of time multiplied squared error is done in the modell loop. In systems without delay time a multidimensional Newton method is used, in systems with delay time a numerical optimization method has to be used. Identification and optimization is repeated for all interesting operation states. The calculated values of the variables are transformed into analog functions by curve fitting methods. Therefore the digital computer isn't any longer necessary.

The given method can be used for continuous and discrete systems with and without delay time.

EXTREMUM-SEEKING REGULATOR WITH EXTRAPOLATION

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Compared with classical systems, the extremum seeking regulator described in this paper requires for its conception a greater quantity of "a priori information" (shape of extremal characteristic $(\mathscr{C})$, knowledge on the dynamical properties of the plant), and maintains its stability in presence of fast drifts of the extremal characteristic $(\mathscr{C})$.

Two kinds of extrapolation are used :

- Linear extrapolation of characteristic drift measured during a constant time interval.
- Parabolic extrapolation using the knowledge of two points of a parabol (P), the parameter of which is determinated by a priori information.

Extremum is reached with one or several optimization sequences. An optimization sequence includes four steps :

- One step of $(\mathscr{C})$-drift detection, with constant duration.
- One search step with variable duration, the purpose of which is the determination of two points of $(\mathscr{C})$.
- One control step, with variable duration, which is the result of a computation giving the (P)-extremum position.
- One rest step, with constant duration, for the transiet state finishing.

Principles used for the regulator conception are analysed, and stability problem is studied,

An Optimal Extremum Control System

O.L.R. Jacobs and S.M. Langdon

The optimal control law is derived for a simplified, discrete-time, single-input, extremum control system in which the effects of measurement noise and dynamic lags are neglected. The derivation uses a dynamic programming formulation that is not readily extended to more general cases of extremum control. The resulting optimal control law gives an indication of the general structure of optimal extremum control laws and gives a measure of the best performance that can be achieved for the particular problem investigated.

SELF-ORGANIZATION OF AN EXTREMAL CONTROL SYSTEM

A.G. Ivaknienko, N.V. Khrushcheva, V.I. Neshodovsky

This paper defines meaning of "selforganization" and shows, that difficulties in multimeasurement calculation /"multimeasurement trouble"/ do not show up in selforganized systems, where unifided "elementary algorithms" and "integral actions" are acting.

Given are examples of extremal control stochastic object and practical ways of general disturbance signal and control signal getting.

Notions "state" and "situation" of a control system, which are learned, are defined.

Discernment system is used when controlling a stochastic object by combination principle: it is used as a corrector for quick-acting open loop control circuit.

Selforganization takes form of a self-groundless displacement of discernment system pole prototypes in co-ordinates space of controlled object.

In the beginning, one of possible algorithms of three pole selforganization is shown.

Further, when many poles are studied, a theory is formed about stability of adaptive selforganization process of "pole gas". Process sampling of prototypes /poles/ selforganization of learned system have prooved about mentioned theory,

THE FUNCTIONAL CONTROL OF THE EYE-TRACKING-SYSTEM AND ITS DIGITAL SIMULATION

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As a consequence of the mathematical analysis of comprehensive biological experiments a clear understanding of the functional organisation of the data-processing system of eye-movement has been gained. The entire system may be divided into two components, i.e. into a continuous and a discontinuous (saccadic) system. By means of a special analog computer circuit the the electrically measured eye-movement was separated into these two components, and an external feedback of the components was achieved. By this procedure the adaptive properties of the discontinuous system have been analysed.
The manifold possibilities of extrapolation and prediction of the organism have been generalized in a mathematical model, not only, to enligthen the effectiveness of this control-system, but also to gain, besides the special results, a better insight into the functional principles realized in biological systems. The applicability of this general functional concept has been checked by way of simulation of the eye-tracking-system.

SIMPLIEST SEARCH MECHANISM FOR MUSCLE ACTIVITY CONTROL

M.A. Aizerman, E.A. Andreeva

Discussed are experimental works conducted in the field of general principles used by brain when it controls museles. Tests were conducted on rats, rabbits and men. Special methods when live organism was connected into network comprehended by feedback, permited for development of artificial duty at which the brain has to solve a searching task which came from the outside, using only one or two muscles.
Control process was studied when searching for minimum pain irritation, with the help of only one muscle or two not connected muscles and work of two antagonistic muscles.
Bassing on those experiments, model illustrations of control rules realised at a/m searching activity, was worked out.

On-line parameter estimation of the human transfer in a man-bicycle system.

The stabilising phenomenon of a bicycle rider is reported.
The work has been started by building a bicycle simulator, which lacks the forward motion. However, the effects thereof on the dynamics of the simulator are taken into account.
As the most significant variable to transmit information about the state of the simulator to the human operator, the angle between bicycle frame and vertical is observed.
Two actions of the bicycle rider, viz. the movements of the upper body and the handle bar are considered as being the actions of the rider on the simulator.
The human transfer function has been determined by using a parameter estimation technique. The mathematical model of the behaviour of the human operator has been considered as consisting of a second order system and a delay time with time-dependent parameters.
These unknown quantities of the linear model are adjusted on-line according to a quadratic performance criterium. The modelling technique has been achieved with the aid of a small digital computer (core memory of 4096 words, 12 bits, cycle time 1.5 μ sec).
It is shown that the method mentioned before is a useful tool for on-line determination of the characteristics of a human operator, balancing a bicycle simulator.

A. van Lunteren

H.G. Stassen

DYNAMICS OF DRIVER/VEHICLE STEERING CONTROL

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The viewpoint and principles of guidance and control theory provide the basis for analyzing the dynamics of driver steering control of motor vehicles. The resultant driver/vehicle system has as its elements the vehicle equations of motion, experimentally derived models for the human operator's dynamic response characteristics, and descriptions of the roadway environment. A variety of single-loop and multiloop systems are synthesized and examined to select several good, simple, and likely alternative configurations: time-advanced lateral deviation, which has a primary outer-loop feedback of lateral position in the lane with lead equalization provided by perceptual preview along the future track of the vehicle; path angle (or rate) plus inertial lateral deviation, which contains a path angle inner loop and a lateral position outer loop; and heading angle (or rate) plus inertial lateral deviation, which has both heading angle and lateral position feedback loops. These do not include all the possible multiloop driver/vehicle structures potentially capable of satisfying guidance and control requirements, but they do provide good performance in command-following and disturbance regulation, insensitivity to variations in the driver's dynamic adaptation, and good predicted subjective opinion from the driver. They are not inconsistent with perceptual data from recent driving experiments. The resultant models provide a new framework for devising future experiments, and can aid the vehicle and highway design process.

A CLOSED-LOOP NEUROMUSCULAR SYSTEM EXPLANATION OF FORCE-DISTURBANCE REGULATION AND TREMOR DATA*

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An adaptive model has recently been evolved to describe small perturbation operations of neuromuscular actuation systems involved in tracking tasks. This model is compatible with both physiological component data and human operator describing function data. The purpose of this paper is to use this model to explain force-disturbance regulation data and limb tremor data as closed-loop phenomena.

The force-disturbance data available in the literature was taken for a large inertia restraint and various values of muscle tone. The response to a torque impulse has a dominant second-order component which is incompatible with the third-order response expected from the open-loop muscle-load model. However, the muscle spindle feedback of an internal muscle length results in a numerator zero in the limb-response/force-disturbance describing function. This zero varies with set tension in a fashion that is nearly the same as the real pole of the muscle-load system. This approximate pole/zero cancellation thus yields a dominant second-order system whose parameters vary with tension to give a qualitative match to the data.

The limb tremor frequency data available in the literature was for variations in spring rate and muscle tone (no added inertia) and for variations in inertia and muscle tone (with no spring). The spindle feedback of an internal muscle length produces a frequency constraint on the lightly damped high frequency dominant mode. The variations of this mode with muscle tone and manipulator restraint values are consistent with the limb tremor frequency variation data.

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C.D. Barr, E.A. Jones, E.R. Carson, L. Finkelstein

A STUDY OF THE DYNAMICS OF PLASMA PROTEIN METABOLISM

SUMMARY

A mathematical dynamic model of albumin and urea metabolism in humans is obtained. The model is linearized, reduced in size and compared with dynamic tests on patients. The comparison shows that the reduced model agrees with the biological measurements within the limits of experimental error. The investigations demonstrate the applicability of dynamic analysis methods in medical research.

OCULOMOTOR PLANT DYNAMICS: ELECTROMYOGRAPHIC AND TRANSIENT RESPONSES IN THE CAT

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Eye movements were produced by injecting frequency modulated pulse trains into the oculomotor nerve in the cat. Eye movements, (the output of the system) and the electromyogram of the medial rectus muscle (an intermediate output) were measured while using sinusoidal and transient inputs. The muscle appeared to behave normally in all respects. The processes generating the electromyogram were not found to contribute to the minimum phase dynamics represented by the overall system output. Using pulse-step transient inputs resulted in rapid saccadic-like eye movements, thus overcoming inherently slow plant dynamics.