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This book has arisen from efforts over many years to find simple and powerful methods for designing industrial control systems. Experience has shown that the classical transfer-function methods were very suitable for isolated loops, but failed in the multivariable situation. The new state-space methods at first promised success, but came in the end to seem disappointing.

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Fall 2010 16.30/31 5-6 Creating State-Space Models • Most easily created from Nth order differential equations that describe the dynamics • This was the case done before. • Only issue is which set of states to use - there are many choices.

~~16.30 Topic 5: Introduction to state-space models~~

State-space and multivariable theory: Author(s) Rosenbrock, Howard Harry: Publication London : Nelson, 1970. - 265 p. Series (Studies in dynamical systems) Subject code 517; 621-5; 62.01: Subject category Mathematical Physics and Mathematics

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In control engineering, a state-space representation is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations or difference equations. State variables are variables whose values evolve over time in a way that depends on the values they have at any given time and on the externally imposed values of input variables.

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In state-determined systems, the state variables may always be taken as the outputs of integrator blocks. A system of order  $n$  has  $n$  integrators in its block diagram.

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"There are three words that characterize this work: thoroughness, completeness and clarity. The authors are congratulated for taking the time to write an excellent linear systems textbook!" —IEEE Transactions on Automatic Control Linear systems theory plays a broad and fundamental role in electrical, mechanical, chemical and aerospace engineering, communications, and signal processing. A thorough introduction to systems theory with emphasis on control is presented in this self-contained textbook, written for a challenging one-semester graduate course. A solutions manual is available to instructors upon adoption of the text. The book's flexible coverage and self-contained presentation also make it an excellent reference guide or self-study manual. For a treatment of linear systems that focuses primarily on the time-invariant case using streamlined presentation of the material with less formal and more intuitive proofs, please see the authors' companion book entitled A Linear Systems Primer.

This book demonstrates the newly developed Elementary Operations Algorithm (EOA). This is a systematic method for constructing a range of state-space realizations for 2-D systems. The key achievements of the monograph are as follows: - It provides a research-level introduction to the general area and undertakes a comparative critical review of previous approaches. - It gives a



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thorough coverage of the theoretical basis of the EOA algorithm. - It demonstrates the effectiveness of the EOA algorithm, for example, through the use of algebraic symbolic computing (using MAPLE), as well as by comparing this method with common alternatives.

## Algebraic Theory for Multivariable Linear Systems

This book contains a derivation of the subset of stabilizing controllers for analog and digital linear time-invariant multivariable feedback control systems that insure stable system errors and stable controller outputs for persistent deterministic reference inputs that are trackable and for persistent deterministic disturbance inputs that are rejectable. For this subset of stabilizing controllers, the Wiener-Hopf methodology is then employed to obtain the optimal controller for which a quadratic performance measure is minimized. This is done for the completely general standard configuration and methods that enable the trading off of optimality for an improved stability margin and/or reduced sensitivity to plant model uncertainty are described. New and novel results on the optimal design of decoupled (non-interacting) systems are also presented. The results are applied in two examples: the one- and three-degree-of-freedom configurations. These demonstrate that the standard configuration is one encompassing all possible feedback configurations. Each chapter is completed by a group of worked examples, which reveal additional insights and extensions of the theory presented

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in the chapter. Three of the examples illustrate the application of the theory to two physical cases: the depth and pitch control of a submarine and the control of a Rosenbrock process. In the latter case, designs with and without decoupling are compared. This book provides researchers and graduate students working in feedback control with a valuable reference for Wiener-Hopf theory of multivariable design. Basic knowledge of linear systems and matrix theory is required.

A graduate text providing broad coverage of linear multivariable control systems, including several new results and recent approaches.

The state-space approach provides a formal framework where any result or procedure developed for a basic model can be seamlessly applied to a standard formulation written in state-space form. Moreover, it can accommodate with a reasonable effort nonstandard situations, such as observation errors, aggregation constraints, or missing in-sample values. Exploring the advantages of this approach, *State-Space Methods for Time Series Analysis: Theory, Applications and Software* presents many computational procedures that can be applied to a previously specified linear model in state-space form. After discussing the formulation of the state-space model, the book illustrates the flexibility of the state-space representation and covers the main state estimation algorithms: filtering and smoothing. It then shows how to compute the Gaussian likelihood for unknown coefficients in the state-space matrices of a given model before introducing

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subspace methods and their application. It also discusses signal extraction, describes two algorithms to obtain the VARMAX matrices corresponding to any linear state-space model, and addresses several issues relating to the aggregation and disaggregation of time series. The book concludes with a cross-sectional extension to the classical state-space formulation in order to accommodate longitudinal or panel data. Missing data is a common occurrence here, and the book explains imputation procedures necessary to treat missingness in both exogenous and endogenous variables. Web Resource The authors' E4 MATLAB® toolbox offers all the computational procedures, administrative and analytical functions, and related materials for time series analysis. This flexible, powerful, and free software tool enables readers to replicate the practical examples in the text and apply the procedures to their own work.

model's predictive capability? These are some of the questions that need to be answered in proposing any time series model construction method. This book addresses these questions in Part II. Briefly, the covariance matrices between past data and future realizations of time series are used to build a matrix called the Hankel matrix. Information needed for constructing models is extracted from the Hankel matrix. For example, its numerically determined rank will be the dimension of the state model. Thus the model dimension is determined by the data, after balancing several sources of error for such model construction. The covariance matrix of the model forecasting error vector is determined by solving a certain

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matrix Riccati equation. This matrix is also the covariance matrix of the innovation process which drives the model in generating model forecasts. In these model construction steps, a particular model representation, here referred to as balanced, is used extensively. This mode of model representation facilitates error analysis, such as assessing the error of using a lower dimensional model than that indicated by the rank of the Hankel matrix. The well-known Akaike's canonical correlation method for model construction is similar to the one used in this book. There are some important differences, however. Akaike uses the normalized Hankel matrix to extract canonical vectors, while the method used in this book does not normalize the Hankel matrix.

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