

# CHEM-E7190/2024: Exercise 11 Part 2/2 - Luenberger observer [EXTRA] - Solutions

1. Design a Luenberger observer for the following state-space system. Implement the code and simulate the system in Matlab.

$$\begin{aligned}x(k+1) &= \begin{bmatrix} 1.8097 & -0.8187 \\ 1 & 0 \end{bmatrix} x(k) + \begin{bmatrix} 0.5 \\ 0 \end{bmatrix} u(k) \\ y(k) &= [0.1810 \quad -0.1810] x(k) + [0] u(k)\end{aligned}$$

*Hint: First, check the observability of the system by computing the observability matrix. Then, select desired observer poles and use pole placement to compute the observer gain matrix  $L$ .*

2. The dynamic equations of the stirred tank system in state-space form are the following:

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix} -0.5 & 0 \\ 0 & -1 \end{bmatrix} x(t) + \begin{bmatrix} 1 & 0 & 0 \\ -0.1 & 1 & 1 \end{bmatrix} w(t) \\ y(t) &= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x(t) + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} w(t)\end{aligned}$$

Design a Luenberger observer for the system. Implement the code and simulate the system in Matlab.

*Hint: Since all states are measured (as indicated by the identity matrix in  $C$ ), consider modifying the problem by assuming one state is not measured. Then, compute the observability matrix and design the observer accordingly.*

3. Calculate the observer gains for the following system when the desired characteristic equation is  $(\lambda + 9)(\lambda + 10)$

$$\begin{aligned}\dot{x}(t) &= \begin{bmatrix} -1 & 1 \\ 2 & -4 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t) \\ y(t) &= [1 \quad 0] x(t)\end{aligned}$$

*Hint: Verify observability by constructing the observability matrix. Then, set up the characteristic equation of  $(A - LC)$  and equate it to the desired characteristic equation to solve for the observer gains*

$$L = \begin{bmatrix} l_1 \\ l_2 \end{bmatrix}.$$

*Solution*

**Observability**

$$\begin{aligned}CA &= [1 \quad 0] \begin{bmatrix} -1 & 1 \\ 2 & -4 \end{bmatrix} = [-1 \quad 1] \\ O &= \begin{bmatrix} C \\ CA \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1 & 1 \end{bmatrix} \text{rank}(O) = 2 = N_o\end{aligned}$$

**Characteristic equation**

$$\begin{aligned}A - LC &= \begin{bmatrix} -1 & 1 \\ 2 & -4 \end{bmatrix} - \begin{bmatrix} l_1 \\ l_2 \end{bmatrix} [1 \quad 0] = \begin{bmatrix} -1-l_1 & 1 \\ 2-l_2 & -4 \end{bmatrix} \\ |\lambda I - (A - LC)| &= \begin{vmatrix} \lambda + 1 + l_1 & -1 \\ -2 + l_2 & \lambda + 4 \end{vmatrix} \\ (\lambda + 1 + l_1)(\lambda + 4) - (-1)(-2 + l_2) &= \lambda^2 + (5 + l_1)\lambda + 4(1 + l_1) + l_2 - 2\end{aligned}$$

# Luenberger Chapter 2 Problem

**Stephen Boyd, Lieven Vandenberghe**



## **Luenberger Chapter 2 Problem:**

**H-infinity Control and Estimation of State-multiplicative Linear Systems** Eli Gershon, Uri Shaked, Isaac Yaesh, 2005-06-24 Multiplicative noise appears in systems where the process or measurement noise levels depend on the system state vector. Such systems are relevant for example in radar measurements where larger ranges involve higher noise level. This monograph embodies a comprehensive survey of the relevant literature with basic problems being formulated and solved by applying various techniques including game theory, linear matrix inequalities and Lyapunov parameter dependent functions. Topics covered include convex  $H_2$  and  $H_\infty$  norms analysis of systems with multiplicative noise, state feedback control and state estimation of systems with multiplicative noise, dynamic and static output feedback of stochastic bilinear systems, tracking controllers for stochastic bilinear systems utilizing preview information. Various examples which demonstrate the applicability of the theory to practical control engineering problems are considered; two such examples are taken from the aerospace and guidance control areas. Hybrid Systems: Computation and Control Maria D. Di Benedetto, Alberto L. Sangiovanni-Vincentelli, 2003-06-29 This volume contains the proceedings of the Fourth Workshop on Hybrid Systems: Computation and Control HSCC 2001 held in Rome, Italy, on March 28-30, 2001. The Workshop on Hybrid Systems attracts researchers from industry and academia interested in modeling, analysis, synthesis and implementation of dynamic and reactive systems involving both discrete, integer, logical, symbolic and continuous behaviors. It is a forum for the discussion of the test developments in all aspects of hybrid systems including formal models and computational representations, algorithms and heuristics, computational tools and new challenging applications. The Fourth HSCC International Workshop continues the series of workshops held in Grenoble, France (HART 97), Berkeley, California, USA (HSCC 98), Nijmegen, The Netherlands (HSCC 99) and Pittsburgh, Pennsylvania, USA (HSCC 2000). Proceedings of these workshops have been published in the Lecture Notes in Computer Science (LNCS) series by Springer-Verlag. In line with the beautiful work that led to the design of the palace in which the workshop was held, Palazzo Lancellotti in Rome, resulting from the collaboration of many artists and architects of different backgrounds, the challenge faced by the hybrid system community is to harmonize and extract the best from two main research areas: computer science and control theory. Applied Dynamic Programming for Optimization of Dynamical Systems Rush D. Robinett III, David G. Wilson, G. Richard Eisler, John E. Hurtado, 2005-07-01 This book presents a range of dynamic programming (DP) techniques applied to the optimization of dynamical systems. **Interactive Operations Research with Maple** Mahmut Parlar, 2012-12-06 Interactive Operations Research with Maple: Methods and Models has two objectives: to provide an accelerated introduction to the computer algebra system Maple and more importantly to demonstrate Maple's usefulness in modeling and solving a wide range of operations research (OR) problems. This book is written in a format that makes it suitable for a one-semester course in operations research, management science or quantitative methods. A number of students in the departments of operations

research management science operations management industrial and systems engineering applied mathematics and advanced MBA students who are specializing in quantitative methods or operations management will find this text useful Experienced researchers and practitioners of operations research who wish to acquire a quick overview of how Maple can be useful in solving OR problems will find this an excellent reference Maple's mathematical knowledge base now includes calculus linear algebra ordinary and partial differential equations number theory logic graph theory combinatorics statistics and transform methods Although Maple's main strength lies in its ability to perform symbolic manipulations it also has a substantial knowledge of a large number of numerical methods and can plot many different types of attractive looking two dimensional and three dimensional graphs After almost two decades of continuous improvement of its mathematical capabilities Maple can now boast a user base of more than 300 000 academics researchers and students in different areas of mathematics science and engineering

*System Identification (SYSID '03)* Paul Van Den Hof,Bo Wahlberg,Siep Weiland,2004-06-29 The scope of the symposium covers all major aspects of system identification experimental modelling signal processing and adaptive control ranging from theoretical methodological and scientific developments to a large variety of engineering application areas It is the intention of the organizers to promote SYSID 2003 as a meeting place where scientists and engineers from several research communities can meet to discuss issues related to these areas Relevant topics for the symposium program include Identification of linear and multivariable systems identification of nonlinear systems including neural networks identification of hybrid and distributed systems Identification for control experimental modelling in process control vibration and modal analysis model validation monitoring and fault detection signal processing and communication parameter estimation and inverse modelling statistical analysis and uncertainty bounding adaptive control and data based controller tuning learning data mining and Bayesian approaches sequential Monte Carlo methods including particle filtering applications in process control systems motion control systems robotics aerospace systems bioengineering and medical systems physical measurement systems automotive systems econometrics transportation and communication systems Provides the latest research on System Identification Contains contributions written by experts in the field Part of the IFAC Proceedings Series which provides a comprehensive overview of the major topics in control engineering

**Discrete Inverse and State Estimation Problems** Carl Wunsch,2006-06-29 The problems of making inferences about the natural world from noisy observations and imperfect theories occur in almost all scientific disciplines This 2006 book addresses these problems using examples taken from geophysical fluid dynamics It focuses on discrete formulations both static and time varying known variously as inverse state estimation or data assimilation problems Starting with fundamental algebraic and statistical ideas the book guides the reader through a range of inference tools including the singular value decomposition Gauss Markov and minimum variance estimates Kalman filters and related smoothers and adjoint Lagrange multiplier methods The final chapters discuss a variety of practical applications to geophysical flow problems Discrete

Inverse and State Estimation Problems is an ideal introduction to the topic for graduate students and researchers in oceanography meteorology climate dynamics and geophysical fluid dynamics It is also accessible to a wider scientific audience the only prerequisite is an understanding of linear algebra

**Road and Off-Road Vehicle System Dynamics Handbook** Gianpiero Mastinu, Manfred Ploechl, 2014-01-06 Featuring contributions from leading experts the Road and Off Road Vehicle System Dynamics Handbook provides comprehensive authoritative coverage of all the major issues involved in road vehicle dynamic behavior While the focus is on automobiles this book also highlights motorcycles heavy commercial vehicles and off road vehicles The authors of the individual chapters both from automotive industry and universities address basic issues but also include references to significant papers for further reading Thus the handbook is devoted both to the beginner wishing to acquire basic knowledge on a specific topic and to the experienced engineer or scientist wishing to have up to date information on a particular subject It can also be used as a textbook for master courses at universities The handbook begins with a short history of road and off road vehicle dynamics followed by detailed state of the art chapters on modeling analysis and optimization in vehicle system dynamics vehicle concepts and aerodynamics pneumatic tires and contact wheel road off road modeling vehicle subsystems vehicle dynamics and active safety man vehicle interaction intelligent vehicle systems and road accident reconstruction and passive safety Provides extensive coverage of modeling simulation and analysis techniques Surveys all vehicle subsystems from a vehicle dynamics point of view Focuses on pneumatic tires and contact wheel road off road Discusses intelligent vehicle systems technologies and active safety Considers safety factors and accident reconstruction procedures Includes chapters written by leading experts from all over the world This text provides an applicable source of information for all people interested in a deeper understanding of road vehicle dynamics and related problems

Convex Optimization Stephen Boyd, Lieven Vandenberghe, 2004-03-08 Convex optimization problems arise frequently in many different fields This book provides a comprehensive introduction to the subject and shows in detail how such problems can be solved numerically with great efficiency The book begins with the basic elements of convex sets and functions and then describes various classes of convex optimization problems Duality and approximation techniques are then covered as are statistical estimation techniques Various geometrical problems are then presented and there is detailed discussion of unconstrained and constrained minimization problems and interior point methods The focus of the book is on recognizing convex optimization problems and then finding the most appropriate technique for solving them It contains many worked examples and homework exercises and will appeal to students researchers and practitioners in fields such as engineering computer science mathematics statistics finance and economics

**Analysis and Design of Descriptor Linear Systems** Guang-Ren Duan, 2010-09-14 Descriptor linear systems theory is an important part in the general field of control systems theory and has attracted much attention in the last two decades In spite of the fact that descriptor linear systems theory has been a topic very rich in content there have been only a few books

on this topic This book provides a systematic introduction to the theory of continuous time descriptor linear systems and aims to provide a relatively systematic introduction to the basic results in descriptor linear systems theory The clear representation of materials and a large number of examples make this book easy to understand by a large audience General readers will find in this book a comprehensive introduction to the theory of descriptive linear systems Researchers will find a comprehensive description of the most recent results in this theory and students will find a good introduction to some important problems in linear systems theory

**Introduction to Nonlinear Control** Christopher M. Kellett, Philipp Braun, 2023-06-27 An introductory text on the analysis control and estimation of nonlinear systems appropriate for advanced undergraduate and graduate students This self contained and accessible introduction to the concepts and techniques used for nonlinear feedback systems offers a holistic treatment suitable for use in both advanced undergraduate and graduate courses students need only some familiarity with differential equations and linear algebra to understand the material presented The text begins with an overview of stability and Lyapunov methods for nonlinear systems with Lyapunov's second method revisited throughout the book as a connective thread Other introductory chapters cover linear systems frequency domain methods and discrete time systems Building on this background material the book provides a broad introduction to the basic ideas underpinning major themes of research in nonlinear control including input to state stability sliding mode control adaptive control feedback linearization and robust output regulation Chapters also cover observer design and estimation for nonlinear systems The text is notable for its coverage of nonlinear model predictive control and its introduction to the use of linear matrix inequalities and semidefinite programming coupled with their use in modern antiwindup designs First text on nonlinear control appropriate for undergraduates Suitable both for students preparing for rigorous graduate study and for those entering technical fields outside of academia Unique in its coverage of recent research topics Pedagogical features including extensive chapter summaries examples and appendixes with definitions results and MATLAB applications

**Continuous Nonlinear Optimization for Engineering Applications in GAMS Technology** Neculai Andrei, 2017-12-04 This book presents the theoretical details and computational performances of algorithms used for solving continuous nonlinear optimization applications imbedded in GAMS Aimed toward scientists and graduate students who utilize optimization methods to model and solve problems in mathematical programming operations research business engineering and industry this book enables readers with a background in nonlinear optimization and linear algebra to use GAMS technology to understand and utilize its important capabilities to optimize algorithms for modeling and solving complex large scale continuous nonlinear optimization problems or applications Beginning with an overview of constrained nonlinear optimization methods this book moves on to illustrate key aspects of mathematical modeling through modeling technologies based on algebraically oriented modeling languages Next the main feature of GAMS an algebraically oriented language that allows for high level algebraic representation of mathematical optimization models is introduced to model and

solve continuous nonlinear optimization applications More than 15 real nonlinear optimization applications in algebraic and GAMS representation are presented which are used to illustrate the performances of the algorithms described in this book Theoretical and computational results methods and techniques effective for solving nonlinear optimization problems are detailed through the algorithms MINOS KNITRO CONOPT SNOPT and IPOPT which work in GAMS technology *State Estimation and Stabilization of Nonlinear Systems* Abdellatif Ben Makhlouf, Mohamed Ali Hammami, Omar Naifar, 2023-11-06 This book presents the separation principle which is also known as the principle of separation of estimation and control and states that under certain assumptions the problem of designing an optimal feedback controller for a stochastic system can be solved by designing an optimal observer for the system's state which feeds into an optimal deterministic controller for the system Thus the problem may be divided into two halves which simplifies its design In the context of deterministic linear systems the first instance of this principle is that if a stable observer and stable state feedback are built for a linear time invariant system LTI system hereafter then the combined observer and feedback are stable The separation principle does not true for nonlinear systems in general Another instance of the separation principle occurs in the context of linear stochastic systems namely that an optimum state feedback controller intended to minimize a quadratic cost is optimal for the stochastic control problem with output measurements The ideal solution consists of a Kalman filter and a linear quadratic regulator when both process and observation noise are Gaussian The term for this is linear quadratic Gaussian control More generally given acceptable conditions and when the noise is a martingale with potential leaps a separation principle also known as the separation principle in stochastic control applies when the noise is a martingale with possible jumps **Multivariable Technological Systems** D.P. Atherton, 2014-06-28 Recent results in the development and application of analysis and design techniques for the control of multivariable systems are discussed in this volume Control Theory and Inverse Problems Kaïs Ammari, Islam Boussaada, Chaker Jammazi, 2024-11-07 This volume presents a timely overview of control theory and inverse problems and highlights recent advances in these active research areas The chapters are based on talks given at the spring school Control Theory Inverse Problems held in Monastir Tunisia in May 2023 In addition to providing a snapshot of these two areas chapters also highlight breakthroughs on more specific topics such as Control of hyperbolic systems The Helffer Nier Conjecture Rapid stabilization of the discretized Vlasov system Exponential stability of a delayed thermoelastic system Control Theory and Inverse Problems will be a valuable resource for both established researchers as well as more junior members of the community **Risk-sensitive Investment Management** Mark H A Davis, Sebastien Lleo, 2014-07-21 Over the last two decades risk sensitive control has evolved into an innovative and successful framework for solving dynamically a wide range of practical investment management problems This book shows how to use risk sensitive investment management to manage portfolios against an investment benchmark with constraints and with assets and liabilities It also addresses model implementation issues in parameter estimation and numerical methods Most importantly it

shows how to integrate jump diffusion processes which are crucial to model market crashes With its emphasis on the interconnection between mathematical techniques and real world problems this book will be of interest to both academic researchers and money managers Risk sensitive investment management links stochastic control and portfolio management Because of its distinct emphasis on integrating advanced theoretical concepts into practical dynamic investment management tools this book stands out from the existing literature in fundamental ways It goes beyond mainstream research in portfolio management in a traditional static setting The theoretical developments build on contemporary research in stochastic control theory but are informed throughout by the need to construct an effective and practical framework for dynamic portfolio management This book fills a gap in the literature by connecting mathematical techniques with the real world of investment management Readers seeking to solve key problems such as benchmarked asset management or asset and liability management will certainly find it useful

**Systems, Automation and Control** Nabil Derbel, Faouzi Derbel, Olfa Kanoun, 2017-12-04 The fifth volume of the Series Advances in Systems Signals and Devices is dedicated to fields related to Systems Automation and Control The scope of this issue encompasses all aspects of the research development and applications of the science and technology in these fields Topics of this issue concern system design system identification biological and economical models control modern control theory nonlinear observers control and application of chaos adaptive non adaptive backstepping control techniques advances in linear control theory systems optimization multivariable control large scale and infinite dimension systems nonlinear control distributed control predictive control geometric control adaptive control optimal and stochastic control robust control neural control fuzzy control intelligent control systems diagnostics fault tolerant control robotics and mechatronics navigation robotics and human machine interaction hierarchical and man machine systems etc Authors are encouraged to submit novel contributions which include results of research or experimental work discussing new developments in the field of systems automation and control The series can be also addressed for editing special issues for novel developments in specific fields The aim of this volume is to promote an international scientific progress in the fields of systems automation and control It provides at the same time an opportunity to be informed about interesting results that have been reported during the international SSD conferences

*Optimization and Nonsmooth Analysis* Frank H. Clarke, 1990-01-01 Mathematical Reviews said of this book that it was destined to become a classical reference This book has appeared in Russian translation and has been praised both for its lively exposition and its fundamental contributions The author first develops a general theory of nonsmooth analysis and geometry which together with a set of associated techniques has had a profound effect on several branches of analysis and optimization Clarke then applies these methods to obtain a powerful unified approach to the analysis of problems in optimal control and mathematical programming Examples are drawn from economics engineering mathematical physics and various branches of analysis in this reprint volume

Constrained Optimization In The Calculus Of Variations and Optimal Control Theory J Gregory, 2018-01-18



The major purpose of this book is to present the theoretical ideas and the analytical and numerical methods to enable the reader to understand and efficiently solve these important optimizational problems. The first half of this book should serve as the major component of a classical one or two semester course in the calculus of variations and optimal control theory. The second half of the book will describe the current research of the authors which is directed to solving these problems numerically. In particular we present new reformulations of constrained problems which leads to unconstrained problems in the calculus of variations and new general accurate and efficient numerical methods to solve the reformulated problems. We believe that these new methods will allow the reader to solve important problems.

### **Parimutuel Applications In Finance**

Ken Baron, Jeffrey Lange, 2006-11-28 Financial intermediaries typically offer derivatives to their customers only when they can hedge the exposures from these transactions. Baron and Lange show that parimutuel auctions can be used by financial intermediaries to offer derivatives without exposing themselves to risk.

**Benchmarking with DEA, SFA, and R** Peter Bogetoft, Lars Otto, 2010-11-19 This book covers recent advances in efficiency evaluations most notably Data Envelopment Analysis DEA and Stochastic Frontier Analysis SFA methods. It introduces the underlying theories, shows how to make the relevant calculations and discusses applications. The aim is to make the reader aware of the pros and cons of the different methods and to show how to use these methods in both standard and non standard cases. Several software packages have been developed to solve some of the most common DEA and SFA models. This book relies on R, a free open source software environment for statistical computing and graphics. This enables the reader to solve not only standard problems but also many other problem variants. Using R one can focus on understanding the context and developing a good model. One is not restricted to predefined model variants and to a one size fits all approach. To facilitate the use of R the authors have developed an R package called Benchmarking which implements the main methods within both DEA and SFA. The book uses mathematical formulations of models and assumptions but it de-emphasizes the formal proofs in part by placing them in appendices or by referring to the original sources. Moreover the book emphasizes the usage of the theories and the interpretations of the mathematical formulations. It includes a series of small examples, graphical illustrations, simple extensions and questions to think about. Also it combines the formal models with less formal economic and organizational thinking. Last but not least it discusses some larger applications with significant practical impacts including the design of benchmarking based regulations of energy companies in different European countries and the development of merger control programs for competition authorities.

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