

# 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 3 Solutions Exercise 1

**Frank L. Lewis**



### **Luenberger Chapter 3 Solutions Exercise 1:**

*Linear and Nonlinear Programming* David G. Luenberger, 2003-09-30 The original edition of this book was celebrated for its coverage of the central concepts of practical optimization techniques This updated edition expands and illuminates the connection between the purely analytical character of an optimization problem expressed by properties of the necessary conditions and the behavior of algorithms used to solve a problem Incorporating modern theoretical insights this classic text is even more useful

**Nonlinear Functional Analysis and its Applications** E. Zeidler, 2013-12-11 As long as a branch of knowledge offers an abundance of problems it is full of vitality David Hilbert Over the last 15 years I have given lectures on a variety of problems in nonlinear functional analysis and its applications In doing this I have recommended to my students a number of excellent monographs devoted to specialized topics but there was no complete survey type exposition of nonlinear functional analysis making available a quick survey to the wide range of readers including mathematicians natural scientists and engineers who have only an elementary knowledge of linear functional analysis I have tried to close this gap with my five part lecture notes the first three parts of which have been published in the Teubner Texte series by Teubner Verlag Leipzig 1976 1977 and 1978 The present English edition was translated from a completely rewritten manuscript which is significantly longer than the original version in the Teubner Texte series The material is organized in the following way Part I Fixed Point Theorems Part II Monotone Operators Part III Variational Methods and Optimization Parts IV jV Applications to Mathematical Physics The exposition is guided by the following considerations a What are the supporting basic ideas and what intrinsic interrelations exist between them 3 In what relation do the basic ideas stand to the known propositions of classical analysis and linear functional analysis y What typical applications are there VII Preface viii Special emphasis is placed on motivation

Equitable Resource Allocation Hanan Luss, 2012-09-11 A unique book that specifically addresses equitable resource allocation problems with applications in communication networks manufacturing emergency services and more Resource allocation problems focus on assigning limited resources in an economically beneficial way among competing activities Solutions to such problems affect people and everyday activities with significant impact on the private and public sectors and on society at large Using diverse application areas as examples Equitable Resource Allocation Models Algorithms and Applications provides readers with great insight into a topic that is not widely known in the field Starting with an overview of the topics covered the book presents a large variety of resource allocation models with special mathematical structures and provides elegant efficient algorithms that compute optimal solutions to these models Authored by one of the leading researchers in the field Equitable Resource Allocation Is the only book that provides a comprehensive exposition of equitable resource allocation problems Presents a collection of resource allocation models with applications in communication networks transportation content distribution manufacturing emergency services and more Exhibits practical algorithms for solving a variety of resource allocation models Uses real world applications and examples to explain important

concepts Includes end of chapter exercises Bringing together much of the equitable resource allocation research from the past thirty years this book is a valuable reference for anyone interested in solving diverse optimization problems

**Nonlinear Programming** Mokhtar S. Bazaraa, Hanif D. Sherali, C. M. Shetty, 2013-06-12 COMPREHENSIVE COVERAGE OF NONLINEAR PROGRAMMING THEORY AND ALGORITHMS THOROUGHLY REVISED AND EXPANDED Nonlinear Programming Theory and Algorithms now in an extensively updated Third Edition addresses the problem of optimizing an objective function in the presence of equality and inequality constraints Many realistic problems cannot be adequately represented as a linear program owing to the nature of the nonlinearity of the objective function and or the nonlinearity of any constraints The Third Edition begins with a general introduction to nonlinear programming with illustrative examples and guidelines for model construction Concentration on the three major parts of nonlinear programming is provided Convex analysis with discussion of topological properties of convex sets separation and support of convex sets polyhedral sets extreme points and extreme directions of polyhedral sets and linear programming Optimality conditions and duality with coverage of the nature interpretation and value of the classical Fritz John FJ and the Karush Kuhn Tucker KKT optimality conditions the interrelationships between various proposed constraint qualifications and Lagrangian duality and saddle point optimality conditions Algorithms and their convergence with a presentation of algorithms for solving both unconstrained and constrained nonlinear programming problems Important features of the Third Edition include New topics such as second interior point methods nonconvex optimization nondifferentiable optimization and more Updated discussion and new applications in each chapter Detailed numerical examples and graphical illustrations Essential coverage of modeling and formulating nonlinear programs Simple numerical problems Advanced theoretical exercises The book is a solid reference for professionals as well as a useful text for students in the fields of operations research management science industrial engineering applied mathematics and also in engineering disciplines that deal with analytical optimization techniques The logical and self contained format uniquely covers nonlinear programming techniques with a great depth of information and an abundance of valuable examples and illustrations that showcase the most current advances in nonlinear problems

**Linear Algebra and Its Applications** Gilbert Strang, 1976 This text combines the underlying theory discussions with examples from electrical engineering computer science physics biology and economics **Optimal and Robust**

**Estimation** Frank L. Lewis, Lihua Xie, Dan Popa, 2017-12-19 More than a decade ago world renowned control systems authority Frank L Lewis introduced what would become a standard textbook on estimation under the title Optimal Estimation used in top universities throughout the world The time has come for a new edition of this classic text and Lewis enlisted the aid of two accomplished experts to bring the book completely up to date with the estimation methods driving today's high performance systems A Classic Revisited Optimal and Robust Estimation With an Introduction to Stochastic Control Theory Second Edition reflects new developments in estimation theory and design techniques As the title suggests the major feature

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**Elementary Differential Equations with Boundary Value Problems** David L. Powers,1985 *Dynamic Macroeconomic Theory* Thomas J. Sargent,1987-02-27 Describes the general equilibrium models that have been built to help interpret time series observations of economic aggregates and predicts the consequence of alternative government interventions **Microeconomic Theory** David G. Luenberger,1995 **Dynamic Economic Analysis** Milton Harris,1987 In industrial organization and labour economics many of the most interesting recent contributions have encompassed explicit dynamics as well as extensive form games This book collects and explains a number of the most widely used techniques in dynamic economic analysis *Mathematical Reviews* ,2003 **Contribution from**

**the Scripps Institution of Oceanography** Scripps Institution of Oceanography,1980 Reprints from various publications *Numerical Analysis* Lee W. Johnson,Ronald Dean Riess,1982 **Nonlinear Programming** Dimitri P. Bertsekas,1999 *Optimal Estimation* Frank L. Lewis,1986-04-15 Describes the use of optimal control and estimation in the design of robots controlled mechanisms and navigation and guidance systems Covers control theory specifically for students with minimal background in probability theory Presents optimal estimation theory as a tutorial with a direct well organized approach and a parallel treatment of discrete and continuous time systems Gives practical examples and computer simulations Provides enough mathematical rigor to put results on a firm foundation without an overwhelming amount of proofs and theorems

*Mathematical Economics and Operations Research* Joseph Zaremba,1978 Topics in Mathematical Analysis for Economists Knut Sydsæter,1981 Differential equations of first order Complex numbers Algebraic equations Topics in the theory of functions of several variables Integration Static optimization theory Differential equations of higher order

Difference equations **Modern Control Systems** Richard C. Dorf,Robert H. Bishop,2005 Written to be equally useful for all engineering disciplines this book is organized around the concept of control systems theory as it has been developed in the frequency and time domains It provides coverage of classical control employing root locus design frequency and response design using Bode and Nyquist plots It also covers modern control methods based on state variable models including pole placement design techniques with full state feedback controllers and full state observers The book covers several important topics including robust control systems and system sensitivity state variable models controllability and observability computer control systems internal model control robust PID controllers and computer aided design and analysis For all types

of engineers who are interested in a solid introduction to control systems      Automatic Systems for Building the  
Infrastructure in Developing Countries 2001 (knowledge and Technology Transfer) Georgi M. Dimirovski, 2001 This volume  
records the proceedings of the 2nd IFAC Workshop DECOM TT 2001 held in Ohrid Republic of Macedonia 21-23 May 2001  
**Application of Modern Control Theory to the Design of Optimum Aircraft Controllers** Leo J. Power, 1973

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## **Table of Contents Luenberger Chapter 3 Solutions Exercise 1**

1. Understanding the eBook Luenberger Chapter 3 Solutions Exercise 1
  - The Rise of Digital Reading Luenberger Chapter 3 Solutions Exercise 1
  - Advantages of eBooks Over Traditional Books
2. Identifying Luenberger Chapter 3 Solutions Exercise 1
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Luenberger Chapter 3 Solutions Exercise 1
  - User-Friendly Interface
4. Exploring eBook Recommendations from Luenberger Chapter 3 Solutions Exercise 1
  - Personalized Recommendations
  - Luenberger Chapter 3 Solutions Exercise 1 User Reviews and Ratings
  - Luenberger Chapter 3 Solutions Exercise 1 and Bestseller Lists
5. Accessing Luenberger Chapter 3 Solutions Exercise 1 Free and Paid eBooks
  - Luenberger Chapter 3 Solutions Exercise 1 Public Domain eBooks
  - Luenberger Chapter 3 Solutions Exercise 1 eBook Subscription Services
  - Luenberger Chapter 3 Solutions Exercise 1 Budget-Friendly Options

6. Navigating Luenberger Chapter 3 Solutions Exercise 1 eBook Formats
  - ePub, PDF, MOBI, and More
  - Luenberger Chapter 3 Solutions Exercise 1 Compatibility with Devices
  - Luenberger Chapter 3 Solutions Exercise 1 Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Luenberger Chapter 3 Solutions Exercise 1
  - Highlighting and Note-Taking Luenberger Chapter 3 Solutions Exercise 1
  - Interactive Elements Luenberger Chapter 3 Solutions Exercise 1
8. Staying Engaged with Luenberger Chapter 3 Solutions Exercise 1
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Luenberger Chapter 3 Solutions Exercise 1
9. Balancing eBooks and Physical Books Luenberger Chapter 3 Solutions Exercise 1
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Luenberger Chapter 3 Solutions Exercise 1
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Luenberger Chapter 3 Solutions Exercise 1
  - Setting Reading Goals Luenberger Chapter 3 Solutions Exercise 1
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Luenberger Chapter 3 Solutions Exercise 1
  - Fact-Checking eBook Content of Luenberger Chapter 3 Solutions Exercise 1
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements



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