

# Nonlinear System Analysis

## Practice Problems

1. Let  $y(t)$  be the population of fish at a lake and it is governed by the equation  $\dot{y} = y(4 - y) - k$  where  $k > 0$  is the rate of fishing.

Find the critical rate of harvesting above which the entire fish population becomes extinct. Find the type of bifurcation at that critical harvest rate.

**Solution:**

The fixed points occur when  $y(4 - y) = k$ . It is given by intersection of the line  $y = k$  with the curve  $f(y) = y(4 - y)$  as shown in Figure 1. We see that at low values of  $k$ , say  $k_1$ , there are two fixed points,

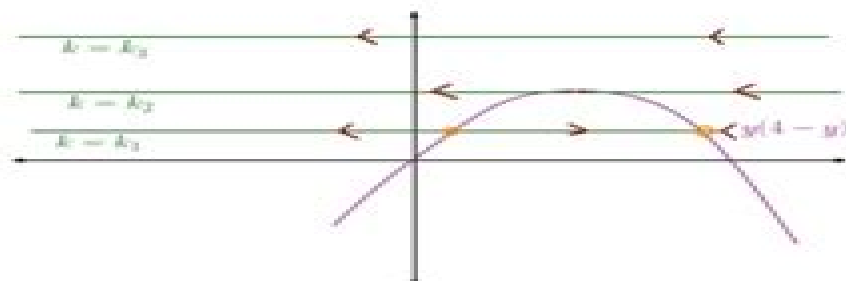


Figure 1

(marked in orange) and there is a stable steady state (stable equilibrium point in the right) of population if it initially were above a threshold (given by the unstable equilibrium point in the left). But they merge at  $k = k_2$  and disappear. So, there is a saddle node bifurcation happening at  $k_2$  as a stable and an unstable fixed point collide and disappear. The precise value is when  $y = k_2 = \text{maximum value of the parabola}$ . The parabolic function  $f(y) = y(4 - y) = 4y - y^2$  attains its maximum at  $y$  where  $f'(y) = 4 - 2y = 0$  and hence at  $y = 2$ , at which  $f(2) = 4$ . So,  $k_2 = 4$ .

2. Sketch the bifurcation diagram and phase portrait for  $\dot{x} = \mu x + x^2 - x^3$ . What would happen if the parameter  $\mu$  is slowly increased from  $-\infty$  to  $\infty$ ?

**Solution:**

The equilibria satisfy  $x(\mu + x^2 - x^3) = 0$  and hence the equilibria are,

$$x = 0$$

$$x^2 = \frac{1 \pm \sqrt{1 + 4\mu}}{2}$$

These roots  $x^2$  are both complex if  $\mu < -\frac{1}{4}$  (hence no roots for  $x$ ), both real and positive if  $-\frac{1}{4} < \mu < 0$  (hence four roots for  $x$ ), and one is real and positive the other real and negative if  $\mu > 0$  (hence only two roots for  $x$ ). It follows that there are no equilibria in addition to  $x = 0$  if  $\mu < -\frac{1}{4}$ , four additional equilibria if  $-\frac{1}{4} < \mu < 0$ , and only two equilibria if  $\mu > 0$ .

$\mu$	Equilibria and type
$\mu < -\frac{1}{4}$	$x = 0$
$-\frac{1}{4} < \mu < 0$	$x = 0$ , four additional equilibria
$\mu > 0$	$x = 0$ and two other equilibria

# Nonlinear System Analysis

**J. Karl Hedrick, Henry Martyn Paynter**



## **Nonlinear System Analysis:**

**Nonlinear Systems Analysis** Mathukumalli Vidyasagar,1993

**Nonlinear Systems Analysis** M.

Vidyasagar,2002-10-01 This text provides a rigorous mathematical analysis of the behavior of nonlinear control systems under a variety of situations Nonlinear Systems Shankar Sastry,2013-04-18 There has been a great deal of excitement in the last ten years over the emergence of new mathematical techniques for the analysis and control of nonlinear systems Witness the emergence of a set of simplified tools for the analysis of bifurcations chaos and other complicated dynamical behavior and the development of a comprehensive theory of geometric nonlinear control Coupled with this set of analytic advances has been the vast increase in computational power available for both the simulation and visualization of nonlinear systems as well as for the implementation in real time of sophisticated real time nonlinear control laws Thus technological advances have bolstered the impact of analytic advances and produced a tremendous variety of new problems and applications that are nonlinear in an essential way Nonlinear control laws have been implemented for sophisticated flight control systems on board helicopters and vertical take off and landing aircraft adaptive nonlinear control laws have been implemented for robot manipulators operating either singly or in cooperation on a multi fingered robot hand adaptive control laws have been implemented for jet engines and automotive fuel injection systems as well as for automated highway systems and air traffic management systems to mention a few examples Bifurcation theory has been used to explain and understand the onset of flutter in the dynamics of aircraft wing structures the onset of oscillations in nonlinear circuits surge and stall in aircraft engines voltage collapse in a power transmission network Nonlinear System Analysis and Identification from Random Data Julius S. Bendat,1990-03-16 Describes procedures to identify and analyze the properties of many types of nonlinear systems from random data measured at the input and output points of physical systems Improvements are offered in applying older techniques and problems that traditionally have been difficult to analyze are solved by new simpler procedures Formulas are stated for optimum nonlinear system identification in both general models consisting of parallel linear bilinear and trilinear systems and special models consisting of parallel linear finite memory square law systems and finite memory cubic systems New results obtained here show when and how to replace complicated single input output nonlinear models with simpler alternative multiple input single output linear models New error analysis formulas are presented to design experiments and to evaluate estimates obtained from measured data Includes many illustrative examples

**Nonlinear Systems: Analysis and Design** Hazel Johnson,2021-11-16 A system where the changes in the output and input are not proportional is called a nonlinear system Most systems are inherently nonlinear in nature and hence nonlinear problems are studied in various fields such as engineering biology physics mathematics etc Unlike simple linear systems nonlinear dynamical systems that describe changes in variables over time may appear chaotic unpredictable or counterintuitive Nonlinear systems are commonly approximated by linear equations since nonlinear dynamical equations are

difficult to solve This process of approximation is called linearization This book provides significant information of this discipline to help develop a good understanding of nonlinear systems and related fields From theories to research to practical applications case studies related to all contemporary topics of relevance to this field have been included herein This book is a vital tool for all researching or studying nonlinear systems as it gives incredible insights into emerging trends and concepts

*Nonlinear System Analysis* Austin Blaquiere,2012-12-02 Nonlinear System Analysis focuses on the study of systems whose behavior is governed by nonlinear differential equations This book is composed of nine chapters that cover some problems that play a major role in engineering and physics The opening chapter briefly introduces the difference between linear and nonlinear systems Considerable chapters are devoted to engineering and physics related problems and their applications to particle accelerators frequency measurements and masers Included in these chapters are important practical problems such as synchronization stability of systems with periodic coefficients and effect of random disturbances The remaining chapters examine random fluctuations of the motion and self oscillators This book is intended primarily for engineers and physicists

*Analysis and Design of Nonlinear Control Systems* Daizhan Cheng,Xiaoming Hu,Tielong Shen,2011-03-28 Analysis and Design of Nonlinear Control Systems provides a comprehensive and up to date introduction to nonlinear control systems including system analysis and major control design techniques The book is self contained providing sufficient mathematical foundations for understanding the contents of each chapter Scientists and engineers engaged in the field of Nonlinear Control Systems will find it an extremely useful handy reference book Dr Daizhan Cheng a professor at Institute of Systems Science Chinese Academy of Sciences has been working on the control of nonlinear systems for over 30 years and is currently a Fellow of IEEE and a Fellow of IFAC he is also the chairman of Technical Committee on Control Theory Chinese Association of Automation

Nonlinear Systems Dongbin Lee,Christos Volos,Timothy Burg,2016-10-19 The book consists mainly of two parts Chapter 1 Chapter 7 and Chapter 8 Chapter 14 Chapter 1 and Chapter 2 treat design techniques based on linearization of nonlinear systems An analysis of nonlinear system over quantum mechanics is discussed in Chapter 3 Chapter 4 to Chapter 7 are estimation methods using Kalman filtering while solving nonlinear control systems using iterative approach Optimal approaches are discussed in Chapter 8 with retarded control of nonlinear system in singular situation and Chapter 9 extends optimal theory to H infinity control for a nonlinear control system Chapters 10 and 11 present the control of nonlinear dynamic systems twin rotor helicopter and 3D crane system which are both underactuated cascaded dynamic systems Chapter 12 applies controls to antisynchronization synchronization in the chaotic models based on Lyapunov exponent theorem and Chapter 13 discusses developed stability analytic approaches in terms of Lyapunov stability The analysis of economic activities especially the relationship between stock return and economic growth is presented in Chapter 14

*Nonlinear Systems Analysis* Prentice Hall PTR,1993-07-01

**The Electrical Engineering**

**Handbook,Second Edition** Richard C. Dorf,1997-09-26 In 1993 the first edition of The Electrical Engineering Handbook set

a new standard for breadth and depth of coverage in an engineering reference work Now this classic has been substantially revised and updated to include the latest information on all the important topics in electrical engineering today Every electrical engineer should have an opportunity to expand his expertise with this definitive guide In a single volume this handbook provides a complete reference to answer the questions encountered by practicing engineers in industry government or academia This well organized book is divided into 12 major sections that encompass the entire field of electrical engineering including circuits signal processing electronics electromagnetics electrical effects and devices and energy and the emerging trends in the fields of communications digital devices computer engineering systems and biomedical engineering A compendium of physical chemical material and mathematical data completes this comprehensive resource Every major topic is thoroughly covered and every important concept is defined described and illustrated Conceptually challenging but carefully explained articles are equally valuable to the practicing engineer researchers and students A distinguished advisory board and contributors including many of the leading authors professors and researchers in the field today assist noted author and professor Richard Dorf in offering complete coverage of this rapidly expanding field No other single volume available today offers this combination of broad coverage and depth of exploration of the topics The Electrical Engineering Handbook will be an invaluable resource for electrical engineers for years to come

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The orthogonal least squares algorithm that allows models to be built term by term where the error reduction ratio reveals the percentage contribution of each model term Statistical and qualitative model validation methods that can be applied to any model class Generalised frequency response functions which provide significant insight into nonlinear behaviours A completely new class of filters that can move split spread and focus energy The response spectrum map and the study of sub harmonic and severely nonlinear systems Algorithms that can track rapid time variation in both linear and nonlinear systems The important class of spatio temporal systems that evolve over both space and time Many case study examples from modelling space weather through identification of a model of the visual processing system of fruit flies to tracking causality in EEG data are all included to demonstrate how easily the methods can be applied in practice and to show the insight that the algorithms reveal even for complex systems NARMAX algorithms provide a fundamentally different approach to nonlinear system identification and signal processing for nonlinear systems NARMAX methods provide models that are transparent which can easily be analysed and which can be used to solve real problems This book is intended for graduates postgraduates and researchers in the sciences and engineering and also for users from other fields who have collected data and who wish to identify models to help to understand the dynamics of their systems

### **Stability and Stabilization of Nonlinear Systems**

Iasson Karafyllis,Zhong-Ping Jiang,2011-04-02 Recently the subject of nonlinear control systems analysis has grown rapidly and this book provides a simple and self contained presentation of their stability and feedback stabilization which enables the reader to learn and understand major techniques used in mathematical control theory In particular the important techniques of proving global stability properties are presented closely linked with corresponding methods of nonlinear feedback stabilization a general framework of methods for proving stability is given thus allowing the study of a wide class of nonlinear systems including finite dimensional systems described by ordinary differential equations discrete time systems systems with delays and sampled data systems approaches to the proof of classical global stability properties are extended to non classical global stability properties such as non uniform in time stability and input to output stability and new tools for stability analysis and control design of a wide class of nonlinear systems are introduced The presentational emphasis of Stability and Stabilization of Nonlinear Systems is theoretical but the theory s importance for concrete control problems is highlighted with a chapter specifically dedicated to applications and with numerous illustrative examples Researchers working on nonlinear control theory will find this monograph of interest while graduate students of systems and control can also gain much insight and assistance from the methods and proofs detailed in this book

### *Nonlinear System Identification* Oliver

Nelles,2001 Written from an engineering point of view this book covers the most common and important approaches for the identification of nonlinear static and dynamic systems The book also provides the reader with the necessary background on optimization techniques making it fully self contained The new edition includes exercises

### *Nonlinear Systems and Controls*

Jürgen Adamy,2022-12-01 This textbook gives a clear introduction to the theory and application of nonlinear systems and

controls The author introduces and explains the methods of nonlinear control which are becoming increasingly important in research and industrial applications The main features of the book are the comprehensive presentation of the theory excellent comprehensibility the many example applications and more than a hundred exercises with solutions They are illustrated by many color diagrams This book is aimed at advanced engineering students and engineers in industry

Fundamentals of Control Engineering Aniruddh Mohan, 2025-02-20 Fundamentals of Control Engineering explores the evolving landscape of control engineering covering classical principles and advanced methodologies Authored by experts this book provides a comprehensive understanding of control systems principles applications and challenges It adopts a multifaceted approach covering classical control theory modern strategies and specialized topics like quantum control intelligent systems and biomedical control Each chapter balances theoretical principles with practical applications making it suitable for students researchers and engineers The inclusion of advanced topics such as quantum control and intelligent systems reflects emerging technologies reshaping the field Practical examples and case studies showcase control engineering's relevance in various industries while interdisciplinary perspectives emphasize integrating control principles with fields like AI quantum mechanics and healthcare The book also addresses ethical considerations reliability issues and quantum coherence providing a holistic view of the field's opportunities and hurdles Fundamentals of Control Engineering is a valuable resource for understanding the multidisciplinary facets of control systems ideal for students researchers and professionals

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