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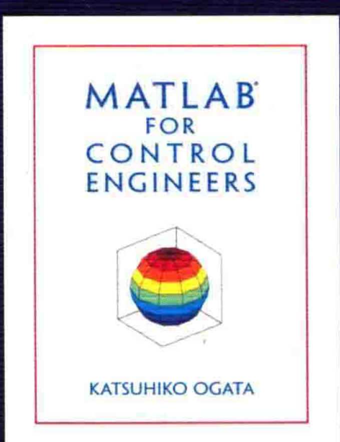
控制理论MATLAB教程

MATLAB for Control Engineers

英文版



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電子工業出版社
PUBLISHING HOUSE OF ELECTRONICS INDUSTRY
http://www.phei.com.cn

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北京 · BEIJING

内容简介

本书系统讲述基于MATLAB的控制系统分析和设计方法。全书共7章，第1章总体介绍MATLAB，第2章为读者提供了在应用MATLAB分析和设计控制系统之前所应掌握的预备知识，第3章详细讨论了如何应用MATLAB获得动态系统在时域信号作用下的瞬态响应，第4章和第5章分别讲解了如何运用MATLAB进行根轨迹和频域方法的分析和设计，第6章讨论了通过MATLAB处理的状态空间设计问题，如极点配置和状态观测器，第7章提供了控制系统设计中最优参数组选取的计算方法，全书最后讨论了用MATLAB解决二次型最优控制问题的方法。

本书适合自动化专业的本科生、控制科学与工程的研究生作为教材或参考书，也适合从事控制领域工作的科研人员和工程师参考。

版权贸易合同登记号：图字：01-2007-4645

图书在版编目（CIP）数据

控制理论MATLAB教程：英文/（美）尾形克彦（Ogata, K.）著. –北京：电子工业出版社，2008.7

（国外计算机科学教材系列）

ISBN 978-7-121-06888-1

Ⅰ.控… Ⅱ.尾… Ⅲ.控制系统–计算机辅助计算–软件包，MATLAB–高等学校–教材–英文 Ⅳ.TP273

中国版本图书馆CIP数据核字（2008）第084114号

责任编辑：马　岚
印　　刷：北京市天竺颖华印刷厂
装　　订：三河市金马印装有限公司
出版发行：电子工业出版社
　　　　　北京市海淀区万寿路173信箱　邮编：100036
开　　本：787 × 980　1/16　印张：27.75　字数：622千字
印　　次：2008年7月第1次印刷
定　　价：49.00元

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出 版 说 明

21世纪初的5至10年是我国国民经济和社会发展的重要时期，也是信息产业快速发展的关键时期。在我国加入WTO后的今天，培养一支适应国际化竞争的一流IT人才队伍是我国高等教育的重要任务之一。信息科学和技术方面人才的优劣与多寡，是我国面对国际竞争时成败的关键因素。

当前，正值我国高等教育特别是信息科学领域的教育调整、变革的重大时期，为使我国教育体制与国际化接轨，有条件的高等院校正在为某些信息学科和技术课程使用国外优秀教材和优秀原版教材，以使我国在计算机教学上尽快赶上国际先进水平。

电子工业出版社秉承多年来引进国外优秀图书的经验，翻译出版了“国外计算机科学教材系列”丛书，这套教材覆盖学科范围广、领域宽、层次多，既有本科专业课程教材，也有研究生课程教材，以适应不同院系、不同专业、不同层次的师生对教材的需求，广大师生可自由选择和自由组合使用。这些教材涉及的学科方向包括网络与通信、操作系统、计算机组织与结构、算法与数据结构、数据库与信息处理、编程语言、图形图像与多媒体、软件工程等。同时，我们也适当引进了一些优秀英文原版教材，本着翻译版本和英文原版并重的原则，对重点图书既提供英文原版又提供相应的翻译版本。

在图书选题上，我们大都选择国外著名出版公司出版的高校教材，如Pearson Education培生教育出版集团、麦格劳–希尔教育出版集团、麻省理工学院出版社、剑桥大学出版社等。撰写教材的许多作者都是蜚声世界的教授、学者，如道格拉斯·科默（Douglas E. Comer）、威廉·斯托林斯（William Stallings）、哈维·戴特尔（Harvey M. Deitel）、尤利斯·布莱克（Uyless Black）等。

为确保教材的选题质量和翻译质量，我们约请了清华大学、北京大学、北京航空航天大学、复旦大学、上海交通大学、南京大学、浙江大学、哈尔滨工业大学、华中科技大学、西安交通大学、国防科学技术大学、解放军理工大学等著名高校的教授和骨干教师参与了本系列教材的选题、翻译和审校工作。他们中既有讲授同类教材的骨干教师、博士，也有积累了几十年教学经验的老教授和博士生导师。

在该系列教材的选题、翻译和编辑加工过程中，为提高教材质量，我们做了大量细致的工作，包括对所选教材进行全面论证；选择编辑时力求达到专业对口；对排版、印制质量进行严格把关。对于英文教材中出现的错误，我们通过与作者联络和网上下载勘误表等方式，逐一进行了修订。

此外，我们还将与国外著名出版公司合作，提供一些教材的教学支持资料，希望能为授课老师提供帮助。今后，我们将继续加强与各高校教师的密切联系，为广大师生引进更多的国外优秀教材和参考书，为我国计算机科学教学体系与国际教学体系的接轨做出努力。

电子工业出版社

导　读

一个偶然的机会，我们阅读了Ogata教授所著新书*MATLAB for Control Engineers*，甚感欣喜。MATLAB语言业已成为控制领域最流行的仿真语言，也是该领域最流行的控制系统分析与设计的计算机辅助工具。目前，MATLAB已被融于控制理论的教学，有些学校甚至专门开设了关于MATLAB应用的课程。本书正是一本不可多得的MATLAB控制理论教程和参考书。

控制类专业的读者在初次接触MATLAB时，通过两种方法都能学会使用MATLAB。一种方法是基本按照MathWorks公司提供的MATLAB使用手册，特别是控制系统工具箱手册中的内容，全面地、分门别类地学习MATLAB命令。在经过较长时间的练习后，读者会比较全面地掌握MATLAB的知识。但是，在按照MATLAB手册的体系进行学习的过程中，读者往往会感觉内容繁杂并且体系庞大。另一种方法是在简单了解MATLAB的基本概念后，按照控制理论中需要解决的问题来学习和使用有关的命令。由于马上就能解决迫切需要解决的问题，读者立即会对要学的内容产生极大的兴趣。通过较短时间的练习，读者就会熟悉相当数量的关键命令；举一反三，也就能很快掌握采用MATLAB解决控制理论问题的能力。这本教材采用的正是后一种方法。

MATLAB教程比比皆是，而介绍如何运用MATLAB软件解决控制问题的书籍却不多见。由于MATLAB已经成为一个庞大的仿真软件，所以让读者在有限的时间内掌握这种软件，并运用其分析、理解和解决控制理论问题，一直是控制专业类师生及应用人员的迫切愿望。所幸的是，本书将MATLAB的介绍和控制理论的学习有机地融合在一起，对需要掌握的MATLAB内容及其深度也把握得恰到好处。读者很容易通过本书来运用MATLAB解决控制问题，而不会被“淹没”到软件的庞大体系之中。

Ogata教授所著的*Modern Control Engineering*一书已成为控制理论的最经典教材之一，据悉其第五版将于2009年问世。这本MATLAB教材的编排与Ogata的现代控制工程教材同步。读者一打开本书，就会有一种似曾相识的亲切感，也许就会有继续研读的愿望。书中除了开篇关于MATLAB基本内容的介绍之外，其他章节的安排基本上与*Modern Control Engineering*一一对应，覆盖了系统建模、瞬态响应分析、根轨迹分析、频域分析以及状态空间控制系统设计方法和优化问题。因此，本书基本上按照控制理论的体系来安排全书内容，体现了控制理论为主体，MATLAB为辅助工具的思想。这种编排方式便于学生同步学习或针对特定控制问题寻求MATLAB处理方法。

本书的主要目的是讲述如何使用MATLAB命令分析和解决控制问题，但书中也较为全面地介绍了控制理论的基本概念和理论，并以MATLAB命令对例题进行全面的分析和求解，所以读者会感到书中的内容特别具有针对性。因此，通过对本书的学习不仅能够掌握利用MATLAB进行控制系统仿真的技能，而且能够加深对控制理论中基本概念的理解，培养控制系统分析和设计的能力。

正是由于本书的上述特点，相信很多读者都会开卷有益。本书不仅可以作为控制系统仿真课程的教材，也可以作为本科生或研究生自动控制原理课程的辅助教材。本书深入浅出的写作风格也使它成为从事控制领域工作的科研人员和工程技术人员的自学用书和参考手册。

清华大学　王诗宓　王峻

Preface

This book is written to assist those students and practicing engineers who wish to study MATLAB to solve control engineering problems. It is written at the level of the senior engineering student.

The book is organized into seven chapters. Chapter 1 presents an introduction to MATLAB. Chapter 2 deals with preliminary materials that the reader must know prior to applying MATLAB to the analysis and design of control systems. Chapter 3 is a detailed discussion of how to apply MATLAB to obtain transient response outputs of dynamic systems to time-domain inputs. Chapter 4 treats root-locus analysis and design with MATLAB. Detailed frequency-response analysis and design with MATLAB are given in Chapter 5. Chapter 6 discusses state-space design problems, such as pole placement and state observers, solved with MATLAB. Finally, Chapter 7 presents a computational approach to obtaining optimal sets of parameter values in connection with control systems design. The book concludes with a discussion of MATLAB's approach to solving quadratic optimal control problems.

The book includes some of the MATLAB materials presented in my previous publications *Modern Control Engineering* (4th ed.) and *System Dynamics* (4th ed.).

All sample problems discussed in the book are given detailed explanations so that the reader will acquire a good understanding of MATLAB's approach to solving the analysis and design problems presented.

The book assumes that the reader has a relatively new version of MATLAB in his or her computer. In plotting root-locus diagrams or Nyquist diagrams with MATLAB, the reader's grid command may produce grid lines or curves different from those presented here; it all depends on the version of MATLAB. (For problems that may arise with regard to grid lines or curves, see the appendix.)

It is hoped that the reader will find this book useful in applying MATLAB to solve many control engineering problems.

KATSUHIKO OGATA

Contents

1

Introduction to MATLAB

1–1 INTRODUCTION

MATLAB® is a matrix-based system for performing mathematical and engineering calculations. We may think of MATLAB as a language of technical computing. All variables handled in MATLAB are matrices. That is, MATLAB has only one data type: a matrix, or rectangular array, of numbers. MATLAB has an extensive set of routines for obtaining graphical outputs.

This section presents background material necessary for the effective use of MATLAB in solving control engineering problems. First, we introduce MATLAB commands and mathematical functions. Then we present matrix operators, relational and logical operators, and special characters used in MATLAB. Finally, we introduce the semicolon operator, MATLAB ways to enter vectors and matrices into the computer, the colon operator, and other important material that we must become familiar with before writing MATLAB programs to solve control engineering problems.

MATLAB is used with a variety of toolboxes. (A toolbox is a collection of special files called M-files.) For control systems analysis and design, MATLAB is used with the control system toolbox. When we refer to MATLAB in this book, we include the basic programs of MATLAB and the control system toolbox.

MATLAB is basically command driven. Therefore, the user must know the commands that are used in solving computational problems. Table 1–1 lists various types of MATLAB commands and predefined functions that are frequently utilized in solving control engineering problems.

Table 1–1 MATLAB Commands and Matrix Functions

Commands and Matrix Functions Commonly Used in Solving Control Engineering Problems	Explanations of What Commands Do and Matrix Functions Mean
abs	Absolute value, complex magnitude.
acker	Compute a state-feedback gain matrix for pole placement, using Ackermann's formula.
angle	Phase angle.
ans	Answer when expression is not assigned.
atan	Arctangent.
axis	Manual axis scaling.
bode	Plot Bode diagram.
clear	Clear workspace.
clf	Clear current figure.
computer	Type of computer.
conj	Complex conjugate.
conv	Convolution, multiplication.
corrcoef	Correlation coefficients.
cos	Cosine.
cosh	Hyperbolic cosine.
cov	Covariance.
ctrb	Compute the controllability matrix.
c2d	Conversion of continuous-time models to discrete-time models.
deconv	Deconvolution, division.
det	Determinant.
diag	Diagonal matrix.
eig	Eigenvalues and eigenvectors.
end	Terminate scope of for, while, switch, try, and if statements.
exit	Terminate program.
exp	Exponential base *e*.
expm	Matrix exponential.
eye	Identity matrix.
feedback	Feedback connection of two LTI models.
filter	Direct filter implementation.
for	Repeat statement(s) a specified number of times.
format long	Fifteen-digit scaled fixed point. (Example: 1.33333333333333)
format long e	Fifteen-digit floating point. (Example: 1.33333333333333e + 000)
format short	Five-digit scaled fixed point. (Example: 1.3333)

Table 1–1 (*continued*)

Commands and Matrix Functions Commonly Used in Solving Control Engineering Problems	Explanations of What Commands Do and Matrix Functions Mean
format short e	Five-digit floating point. (Example: 1.3333e + 000)
freqs	Laplace transform frequency response.
freqz	z-Transform frequency response.
gram	Controllability and observability gramians.
grid	Toggles the major lines of the current axes.
grid off	Removes major and minor grid lines from the current axes.
grid on	Adds major grid lines to the current axes.
help	Lists all primary help topics.
hold	Toggles the hold state.
hold off	Returns to the default mode whereby plot commands erase the previous plots and reset all axis properties before drawing new plots.
hold on	Holds the current plot and all axis properties so that subsequent graphing commands add to the existing graph.
i	$\sqrt{-1}$
imag	Imaginary part.
impulse	Impulse response of LTI models.
inf	Infinity (∞)
inv	Inverse
j	$\sqrt{-1}$
legend	Graph legend.
length	Length of vector.
linspace	Linearly spaced vector.
load	Load workspace variables from disk.
log	Natural logarithm.
loglog	Loglog x–y plot.
logm	Matrix logarithm.
logspace	Logarithmically spaced vector.
log10	Log base 10.
lqe	Linear quadratic estimator design.
lqr	Linear quadratic regulator design.
lsim	Simulate time response of LTI models to arbitrary inputs.
lyap	Solve continuous-time Lyapunov equations.

Table 1–1 *(continued)*

Commands and Matrix Functions Commonly Used in Solving Control Engineering Problems	Explanations of What Commands Do and Matrix Functions Mean
margin	Gain and phase margins and crossover frequencies.
max	Maximum value.
mean	Mean value.
median	Median value.
mesh	Three-dimensional mesh surface.
min	Minimum value.
minreal	Minimal realization and pole–zero cancellation.
NaN	Not a number.
ngrid	Generate grid lines for a Nichols plot.
nichols	Draw the Nichols plot of the LTI model.
num2str	Convert number to string.
nyquist	Plot Nyquist frequency response.
obsv	Compute the observability matrix.
ode45	Solve nonstiff differential equations, medium-order method. (If time constants involved do not vary by several orders of magnitude or more, the differential equations are called nonstiff differential equations.)
ode23	Solve nonstiff differential equations, low-order method.
ode113	Solve nonstiff differential equations, variable-order method.
ones	Constant.
ord2	Generate continuous-time second-order system.
pade	Pade approximation of time delays.
parallel	Parallel interconnection of two LTI models.
pi	Pi(π).
place	Compute a state-feedback gain matrix for pole placement.
plot	Linear *x–y* plot.
polar	Polar plot.
pole	Compute the poles of LTI models.
poly	Convert roots to polynomial.
polyfit	Polynomial curve fitting.
polyval	Polynomial evaluation.
polyvalm	Matrix polynomial evaluation.
printsys	Print system in pretty format.
prod	Product of elements.
pzmap	Pole–zero map of LTI models.

Table 1–1 *(continued)*

Commands and Matrix Functions Commonly Used in Solving Control Engineering Problems	Explanations of What Commands Do and Matrix Functions Mean
quit	Terminate program
rand	Generate random numbers and matrices.
rank	Calculate the rank of a matrix.
real	Real part.
rem	Remainder after division.
residue	Partial-fraction expansion.
rlocfind	Find root-locus gains for a given set of roots.
rlocus	Plot root loci.
rmodel	Generate random stable continuous-time *n*th-order test models.
roots	Polynomial roots.
semilogx	Semilog x–y plot (x-axis logarithmic).
semilogy	Semilog x–y plot (y-axis logarithmic).
series	Interconnect two LTI models in series.
shg	Show graph window.
sign	Signum function.
sin	Sine.
sinh	Hyperbolic sine.
size	Size of matrix.
sqrt	Square root.
sqrtm	Matrix square root.
ss	Create state-space model or convert LTI model to state-space model.
ss2tf	Convert state-space model to transfer-function model.
std	Standard deviation.
step	Plot unit-step response.
subplot	Create axes in tiled positions.
sum	Sum of elements.
switch	Switch among several cases, based on expression.
tan	Tangent.
tanh	Hyperbolic tangent.
text	Arbitrarily positioned text.
tf	Create transfer-function model or convert LTI model to transfer-function model.
tf2ss	Convert transfer-function model to state-space model.
tf2zp	Convert transfer-function model to zero–pole model.
title	Plot title.
trace	Trace of a matrix.

Table 1–1 (*continued*)

Commands and Matrix Functions Commonly Used in Solving Control Engineering Problems	Explanations of What Commands Do and Matrix Functions Mean
who whos	Lists all the variables currently in memory. List all the variables in the current workspace, together with information about their size, bytes, class, etc.
xlabel	*x*-axis label.
ylabel	*y*-axis label.
zero zeros zlabel zpk zp2tf	Transmission zeros of LTI systems. Zeros array. *z*-axis label Create zero–pole–gain models or convert to zero–pole–gain format. Convert zero–pole model to transfer-function model.

Accessing and exiting MATLAB. On most systems, once MATLAB has been installed, execute the command MATLAB to invoke MATLAB. To exit MATLAB, execute the command exit or quit.

MATLAB has an online help facility that may be invoked whenever the need arises. The command help will display a list of predefined functions and operators for which online help is available. The command

```
help 'function name'
```

will give information on the purpose and use of the specific function named. The command

```
help help
```

will give information on how to use the online help.

Matrix operators. The following notation is used in matrix operations (if multiple operations are involved, the order of the arithmetic operations can be altered with the use of parentheses):

+	Addition
−	Subtraction
*	Multiplication
^	Power
'	Conjugate transpose
/ or \	Matrix division
./ or .\	Array division