教育部高等教育司推荐
国外优秀信息科学与技术系列教学用书

自动控制系统

第8版 影印版

Automatic Control Systems

Eighth Edition

- Benjamin C. Kuo
- Farid Golnaraghi

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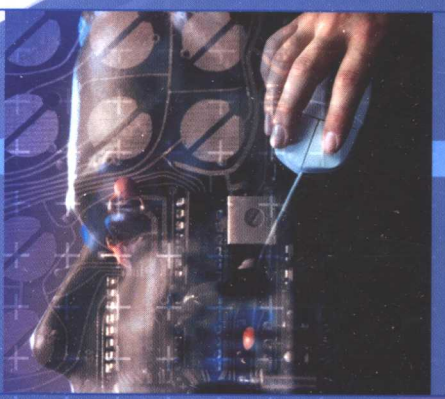

高等教育出版社
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图字：01-2003-5103 号

图书在版编目（CIP）数据

自动控制系统：第 8 版/(美)库沃(Kuo,B.C.)，(美)高那菲（Golnaraghi,F.）著.—影印本. —北京：高等教育出版社，2003.12
ISBN 7-04-013785-2

Ⅰ.自... Ⅱ.①库...②高... Ⅲ.自动控制系统—高等学校.—教材—英文 Ⅳ.TP273

中国版本图书馆 CIP 数据核字（2003）第 104405 号

策划编辑 李 慧 **责任编辑** 李 慧 **封面设计** 王凌波 **责任印制** 宋克学

出版发行	高等教育出版社	**购书热线**	010-64054588
社 址	北京市西城区德外大街 4 号	**免费咨询**	800-810-0598
邮政编码	100011	**网 址**	http://www.hep.edu.cn
总 机	010-82028899		http://www.hep.com.cn
经 销	新华书店北京发行所		
印 刷	北京中科印刷有限公司		
开 本	850×1168 1/16	**版 次**	2003 年 12 月第 1 版
印 张	39.25	**印 次**	2003 年 12 月第 1 次印刷
字 数	500 000	**定 价**	48.50 元

前　言

20 世纪末，以计算机和通信技术为代表的信息科学和技术对世界经济、科技、军事、教育和文化等产生了深刻影响。信息科学技术的迅速普及和应用，带动了世界范围信息产业的蓬勃发展，为许多国家带来了丰厚的回报。

进入 21 世纪，尤其随着我国加入 WTO，信息产业的国际竞争将更加激烈。我国信息产业虽然在 20 世纪末取得了迅猛发展，但与发达国家相比，甚至与印度、爱尔兰等国家相比，还有很大差距。国家信息化的发展速度和信息产业的国际竞争能力，最终都将取决于信息科学技术人才的质量和数量。引进国外信息科学和技术优秀教材，在有条件的学校推动开展英语授课或双语教学，是教育部为加快培养大批高质量的信息技术人才采取的一项重要举措。

为此，教育部要求由高等教育出版社首先开展信息科学和技术教材的引进试点工作。同时提出了两点要求，一是要高水平，二是要低价格。在高等教育出版社和信息科学技术引进教材专家组的努力下，经过比较短的时间，第一批引进的 20 多种教材已经陆续出版。这套教材出版后受到了广泛的好评，其中有不少是世界信息科学技术领域著名专家、教授的经典之作和反映信息科学技术最新进展的优秀作品，代表了目前世界信息科学技术教育的一流水平，而且价格也是最优惠的，与国内同类自编教材相当。

这项教材引进工作是在教育部高等教育司和高教社的共同组织下，由国内信息科学技术领域的专家、教授广泛参与，在对大量国外教材进行多次遴选的基础上，参考了国内和国外著名大学相关专业的课程设置进行系统引进的。其中，John Wiley 公司出版的贝尔实验室信息科学研究中心副总裁 Silberschatz 教授的经典著作《操作系统概念》，是我们经过反复谈判，做了很多努力才得以引进的。William Stallings 先生曾编写了在美国深受欢迎的信息科学技术系列教材，其中有多种教材获得过美国教材和学术著作者协会颁发的计算机科学与工程教材奖，这批引进教材中就有他的两本著作。留美中国学者 Jiawei Han 先生的《数据挖掘》是该领域中具有里程碑意义的著作。由达特茅斯学院的 Thomas Cormen 和麻省理工学院、哥伦比亚大学几位学者共同编著的经典著作《算法导论》，在经历了 11 年的锤炼之后于 2001 年出版了第二版。目前任教于美国 Massachusetts 大学的 James Kurose 教授，曾在美国三所高校先后 10 次获得杰出教师或杰出教学奖，由他主编的《计算机网络》出版后，以其体系新颖、内容先进而倍受欢迎。在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作。这套引进的教材体现了权威性、系统性、先进性和经济性等特点。

教育部也希望国内和国外的出版商积极参与此项工作，共同促进中国信息技术教育和信息产业的发展。我们在与外商的谈判工作中，不仅要坚定不移地引进国外最优秀的教材，而且还

要千方百计地将版权转让费降下来，要让引进教材的价格与国内自编教材相当，让广大教师和学生负担得起。中国的教育市场巨大，外国出版公司和国内出版社要通过扩大发行数量取得效益。

在引进教材的同时，我们还应做好消化吸收，注意学习国外先进的教学思想和教学方法，提高自编教材的水平，使我们的教学和教材在内容体系上，在理论与实践的结合上，在培养学生的动手能力上能有较大的突破和创新。

目前，教育部正在全国35所高校推动示范性软件学院的建设和实施，这也是加快培养信息科学技术人才的重要举措之一。示范性软件学院要立足于培养具有国际竞争力的实用性软件人才，与国外知名高校或著名企业合作办学，以国内外著名IT企业为实践教学基地，聘请国内外知名教授和软件专家授课，还要率先使用引进教材开展教学。

我们希望通过这些举措，能在较短的时间，为我国培养一大批高质量的信息技术人才，提高我国软件人才的国际竞争力，促进我国信息产业的快速发展，加快推动国家信息化进程，进而带动整个国民经济的跨越式发展。

教育部高等教育司

二〇〇二年三月

Dedications

Benjamin C. Kuo

To my family and Pugsley, Baobei, Buppy, and Tuskers

M. Farid Golnaraghi

To my wife, Mitra, for standing by me and for showing me the meaning of true love, and to baby Sophia, the joy of my life.

Preface (Readme)

This is the first time I have written a book for John Wiley & Sons, although it is a revision of an old edition. In 2000 Simon and Schuster was sold to Pearson, and the U.S. Justice Department stipulated the condition of merger was to divest a list of titles of Simon and Schuster. Apparently, *Automatic Control Systems*, 7th Edition, was among the titles. Maybe there are experts at the Justice Department who understood control systems. So, this is a brief history on how *Automatic Control Systems*, after being with Simon Schuster for nearly 40 years suddenly ended up as a book at John Wiley & Sons. However, we couldn't be happier as Wiley authors, and the forced transition has turned out to be a blessing.

In order to bring on new ideas and current material the 8th Edition has brought on a new coauthor, Professor Farid Golnaraghi from the University of Waterloo Ontario, Canada.

What we attempted to do for the revision is to make the book more streamlined while retaining the essential material. We have added more computer-aided tools for students and teachers. The prepublication manuscript has been reviewed by many professors, and most of the relevant suggestions have been adopted.

In the 8th Edition, the following material has been moved into appendices on the CD-ROM. These are

Appendix A: Complex Variable Theory
Appendix B: Differential and Difference Equations
Appendix C: Elementary Matrix Theory and Algebra
Appendix D: Laplace Transform Table
Appendix E: Operational Amplifier
Appendix F: Properties and Construction of the Root Loci
Appendix G: Frequency-Domain Plots
Appendix H: General Nyquist Criterion
Appendix I: Discrete-Data Control Systems
Appendix J: z-Transform Table
Appendix K: **ACSYS** 2002: Description of the Software
Answers to Selected Problems

In addition, the CD-ROM contains the MATLAB™ files for **ACSYS**, which are software tools for solving control-system problems, and Powerpoint files for the illustrations in the text. We have pulled all the material on discrete-data control systems in each chapter and placed it in Appendix I.

The following paragraphs are aimed at three groups: professors who have adopted the book or who we hope will select it as their text; practicing engineers looking for answers to solve their day-to-day design problems; and finally, students who are going to live with the book because it has been assigned for the control-systems course they are taking.

To the Professor: The material assembled in this book is an outgrowth of senior-level control-system courses taught by the authors at their universities throughout their teaching career. The first seven editions have been adopted by hundreds of universities in the United States and around the world, and have been translated into at least six languages.

™MATLAB is a registered trademark of MathWorks Inc.

Practically all the design topics presented in the 7th Edition have been retained. One of the significant changes is that the subject of discrete-data control systems is now in Appendix I on the CD-ROM. We would prefer to teach discrete-data systems as extensions of their analog counterparts. However, realistically, it would be difficult to cover both analog and discrete control systems in a one-semester course.

The software added to this edition is very different from the software accompanying any other control book. Here, through extensive use of MATLAB GUI programming, we have created software that is easy to use. As a result, students will need to focus only on learning control problems, not programming! We also have added two very new applications: SIMLab and Virtual Lab, where students work on realistic problems and conduct speed and position control labs in software environment. In SIMLab, students have access to the system parameters and can alter them (as in any simulation). In Virtual Lab, we have introduced a black-box approach, where the students have no access to the plant parameters and have to use some sort of system identification technique to find them. Through Virtual Lab we have essentially provided students with a realistic online lab with all the problems they would encounter in a real speed- or position-control lab, for example, amplifier saturation, noise, and nonlinearity. We welcome your ideas for the future editions of this book.

Finally, a sample section-by-section a one-semester course is given in the *Instructor's Manual*, which is available from the publisher to qualified instructors. The *Manual* also contains detailed solutions to all the problems in the book.

To Practicing Engineers: This book was written with the readers in mind and is very suitable for self-study. Our objective was to treat subjects clearly and thoroughly. The book does not use the theorem–proof–Q.E.D. style and is without heavy mathematics. The authors have consulted extensively for wide sectors of the industry for many years, and have participated in solving numerous control-systems problems, from aerospace systems to industrial controls, automotive controls, and control of computer peripherals. Although it is difficult to adopt all the details and realism of practical problems in a textbook at this level, some examples and problems reflect simplified versions of real-life systems.

To Students: You have had it now that you have signed up for this course and your professor has assigned this book! You had no say about the choice, although you can form and express your opinion on the book after reading it. Worse yet, one of the reasons that your professor made the selection is because he or she intends to make you work hard. But please don't misunderstand us: what we really mean is that although this is an easy book to study (in our opinion), it is a no-nonsense book. It doesn't have cartoons or nice-looking photographs to amuse you. From here on, it is all business and hard work. You should have had the prerequisites on subjects found in a typical linear-systems course, such as how to solve linear ordinary differential equations, Laplace transform and appplications, and time-response and frequency-domain analysis of linear systems. In this book you will not find too much new mathematics to which you have not been exposed before. What is interesting and challenging is that you are going to learn how to apply some of the mathematics that you have acquired during the last two or three years of study in college. In case you need to review some of the mathematical foundations, you can find them in the appendices on the CD-ROM that accompanies this text. The CD-ROM also contains lots of other goodies, including the **ACSYS** software, which is GUI software that uses MATLAB-based programs for solving linear control systems problems. You will also find the Simulink-based SimLab and Virtual Lab, which will help you to gain understanding of real-world control systems.

This book has numerous illustrative examples. Some of these are deliberately simple for the purpose of illustrating new ideas and subject matter. Some examples are more elaborate, in order to bring the practical world closer to you. Furthermore, the objective of this book is to present a complex subject in a clear and thorough way. One of the important learning

strategies for you as a student is not to rely strictly on the textbook assigned. When studying a certain subject, go to the library and check out a few similar texts to see how other authors treat the same subject. You may gain new perspectives on the subject and discover that one author may treat the material with more care and thoroughness than the others. Do not be distracted by written-down coverage with oversimplified examples. The minute you step into the real world, you will face the design of control systems with nonlinearities and/or time-varying elements as well as orders that can boggle your mind. It may be discouraging to tell you now that strictly linear and first-order systems do not exist in the real world.

Some advanced engineering students in college do not believe that the material they learn in the classroom is ever going to be applied directly in industry. Some of our students come back from field and interview trips totally surprised to find that the material they learned in courses on control systems is actually being used in industry today. They are surprised to find that this book is also a popular reference for practicing engineers. Unfortunately, these fact-finding, eye-opening, and self-motivating trips usually occur near the end of their college days, which is often too late for students to get motivated.

There are many learning aids available to you: The MATLAB-based **ACSYS** software will assist you in solving all kinds of control-systems problems. The SIMLab and Virtual Lab software can be used for simulation of virtual experimental systems. These are all found on the CD-ROM accompanying this text. In addition, the Review Questions and Summary at the end of each chapter should all be useful to you. You should also visit the Web site dedicated to the book, where you will find the errata and other supplemental material.

We hope that you will enjoy this book. It will represent another major textbook acquisition (investment) in your college career. Our advice to you is not to sell it back to the bookstore at the end of the semester. If you do so, but find out later in your professional career that you need to refer to a control systems book, you will have to buy it back at a higher price again.

An Important Note Regarding the ACSYS Software: At the time of publication of this book, there is an issue of compatibility between MATLAB version 6.0 (R12), the student version of MATLAB (R12) and MATLAB version 6.1 (R12.1), and Windows XP. Upon our request Mathworks Inc. issued the following statement:

"The Student Version of MATLAB 6.0 (R12) is not officially supported under Windows XP. For more information on the system requirements for the Student Version of MATLAB 6.0 (R12), please see the following URL:

http://www.mathworks.com/products/studentversion/sys_req.shtml

Currently, there are no plans to officially support the Student Version of MATLAB 6.0 (12) on Windows XP, though our development staff may readdress support for Windows XP on the Student Version in the future."
Further in a statement in the following URL they suggest:

http://www.mathworks.com/support/solutions/data/30479.shtml

"MATLAB 6.1 (R12.1) was released before Windows XP was finalized and thus was not validated under Windows XP. Windows XP will be officially supported in our next release of MATLAB. The system requirements for MATLAB 6.1 (R12.1) can be found at the following URL:

http://www.mathworks.com/products/system.shtml/Windows

In the minimal testing that we have done, we have experienced some incompatibilities with MATLAB 6.1 (R12.1) and Windows XP. There are two possible workarounds that you can do to address these issues:
1. You can use Windows XP in the "Windows Classic Style" mode and/or
2. You can download a new file, hg.dll ...

PLEASE NOTE: The new hg.dll file is not meant for use with the Student Version of MATLAB 6.0 (R12) on Windows XP."

Based on the previous statements, it is our understanding that MATLAB R12 is not compatible with Windows XP and MATLAB version 6.1 (R12.1) may be used with Windows XP with some possible problems.

Further, at the final stages of publication of this book the pre-release version of MATLAB 6.5 R13 became available. The ACSYS software was successfully tested on the pre-release of MATLAB 6.5 R13, and has worked properly using all Microsoft Windows operating systems. It is expected that the student and full versions of MATLAB 6.5 R13 are available in 2003.

As a result, we have decided to release three versions of the ACSYS software, which accompanies this book:

1. **ACSYS** 2002 (R12) is supported by all Microsoft Operating Systems except for Windows XP. The users of the student version of MATLAB (R12) must use this version.
2. **ACSYS** 2002 (R12.1) is supported by all Microsoft Operating Systems, and appear to work fine with the Windows XP. Although we have not observed any problems running MATLAB 6.1 under Windows XP Operating System, Windows XP users may expect to encounter some problems.
3. **ACSYS** 2002 (Pre-release R13) is supported by all Microsoft Operating Systems. This version should work properly with the student and full versions of MATLAB R13 once they are available.

Special Acknowledgments: The authors wish to thank the following reviewers, who have given permission to have their names mentioned. The prepublication reviews have had great impact on the revision project.

Professor B. Ross Barmish, University of Wisconsin
Professor Peter Reischi, San Jose State University
Hy D. Tran, University of New Mexico
Hoss Cyrus Ahmadi, University of British Columbia
Professor Peng-Yung Woo, Northern Illinois University
Professor John L. Crassidis, University at Buffalo
Professor Horacio J. Marquez, University of Alberta
Professor Joseph F. Horn, The Pennsylvania State University
Professor Semyon M. Meerkov, University of Michigan
Professor Bill Diong, University of Texas at El Paso
Professor Swapan Kumar Mukherjee, Regional Institute of Technology
Professor L. F. Yeung, City University of Hong Kong

The authors are indebted to Professor Duane Hanselman at the University of Maine for his valuable suggestions on the revision.

The authors thank Tony Kim, Peter Won and Hamid Karbasi, graduate students at University of Waterloo, for their help with the software development, and Professor Jan Huissoon of the University of Waterloo for his help in creating the SIMLab and Virtual Lab experiments. Farid Golnaraghi also wishes to thank Professor Benjamin Kuo for sharing the pleasure of writing this wonderful book, and for his teachings, patience, and support throughout this experience.

B. C. Kuo; Champaign, Illinois U.S.A.

M. F. Golnaraghi; Waterloo, Ontario, Canada

2002, Year of the Horse

Laplace Transform Table

Laplace Transform $F(s)$	Time Function $f(t)$
1	Unit-impulse function $\delta(t)$
$\frac{1}{s}$	Unit-step function $u_s(t)$
$\frac{1}{s^2}$	Unit-ramp function t
$\frac{n!}{s^{n+1}}$	$t^n (n = \text{positive integer})$
$\frac{1}{s+\alpha}$	$e^{-\alpha t}$
$\frac{1}{(s+\alpha)^2}$	$te^{-\alpha t}$
$\frac{n!}{(s+\alpha)^{n+1}}$	$t^n e^{-\alpha t} (n = \text{positive integer})$
$\frac{1}{(s+\alpha)(s+\beta)}$	$\frac{1}{\beta-\alpha}(e^{-\alpha t} - e^{-\beta t})(\alpha \neq \beta)$
$\frac{s}{(s+\alpha)(s+\beta)}$	$\frac{1}{\beta-\alpha}(\beta e^{-\beta t} - \alpha e^{-\alpha t})(\alpha \neq \beta)$
$\frac{1}{s(s+\alpha)}$	$\frac{1}{\alpha}(1 - e^{-\alpha t})$
$\frac{1}{s(s+\alpha)^2}$	$\frac{1}{\alpha^2}(1 - e^{-\alpha t} - \alpha t e^{-\alpha t})$
$\frac{1}{s^2(s+\alpha)}$	$\frac{1}{\alpha^2}(\alpha t - 1 + e^{-\alpha t})$
$\frac{1}{s^2(s+\alpha)^2}$	$\frac{1}{\alpha^2}\left[t - \frac{2}{\alpha} + \left(t + \frac{2}{\alpha}\right)e^{-\alpha t}\right]$
$\frac{s}{(s+\alpha)^2}$	$(1 - \alpha t)e^{-\alpha t}$

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