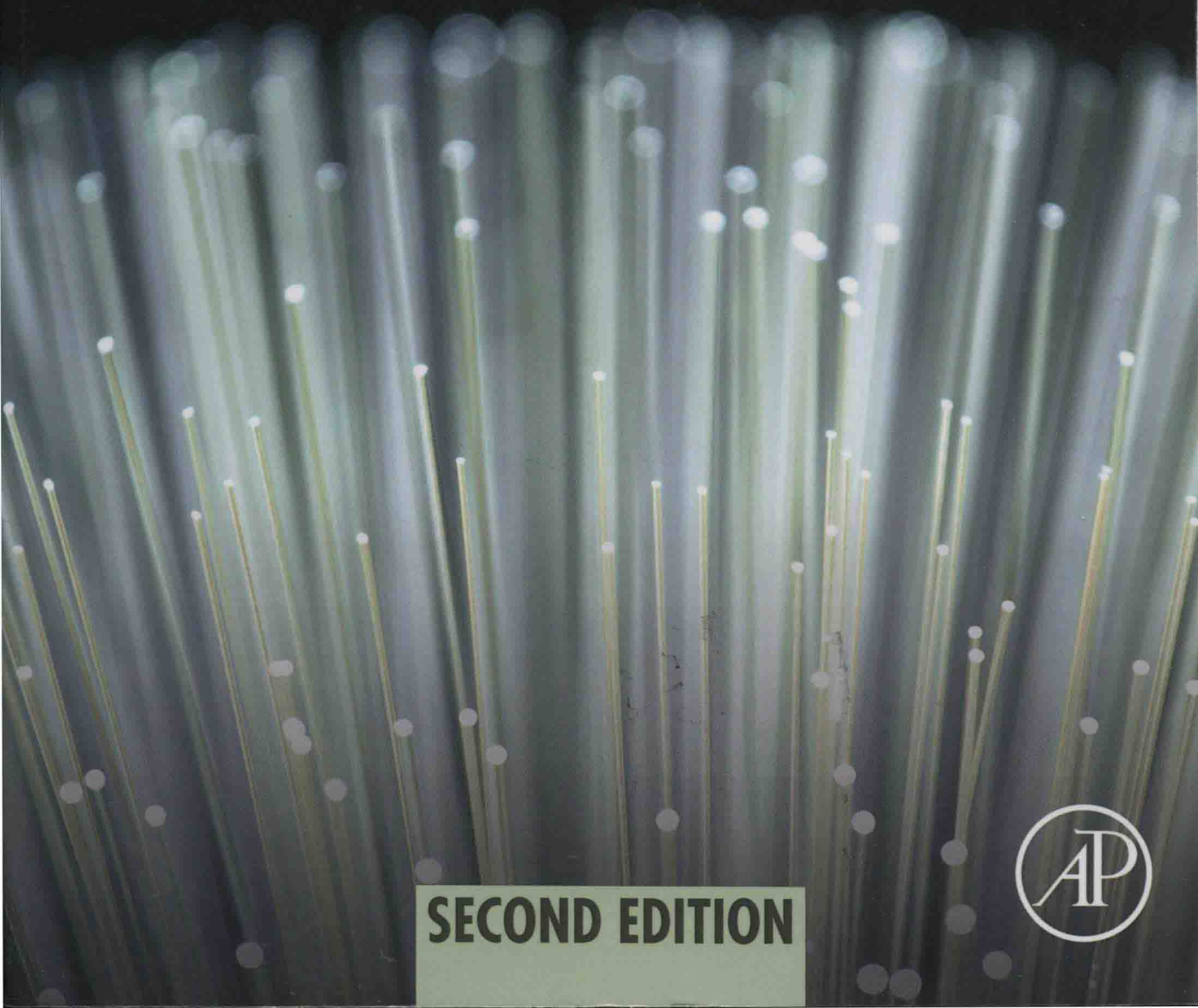
Alan S. Morris | Reza Langari

MEASUREMENT AND INSTRUMENTATION

Theory and Application



SECOND EDITION

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MEASUREMENT AND INSTRUMENTATION

Theory and Application

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This new edition of ***Measurement and Instrumentation: Theory and Application*** has been fully updated to cover the latest developments in measurement technologies, including smart sensors, intelligent instruments, microsensors, digital recorders, displays, and interfaces. The second edition includes expanded and improved discussions of measurement uncertainty and induced measurement noise, as well as coverage of recently developed technologies, including micromachine structures (MEMs and NEMs). A significant increase in worked examples and end-of-chapter problems makes this new edition an even more valuable resource for students and instructors.

KEY FEATURES

- Early coverage of measurement system design provides students with a better framework for understanding the importance of studying measurement and instrumentation
- Includes significant material on data acquisition, sampling theory, and linkage to LabVIEW acquisition/processing software
- Extensive coverage of measurement uncertainty aids students' ability to determine the accuracy of instruments and measurement systems
- Includes the most recent developments in digital test instruments, reflecting real-world test and measurement situations
- Discussion of calibration in all chapters covering the instruments used to measure particular physical variables impresses upon students the importance of this in achieving accurate measurements
- Integrated use of LabVIEW examples and problems enhances students' ability to understand and retain content

ENGINEERING

ISBN 978-0-12-800884-3

9 780128 008843

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ACADEMIC PRESS

An imprint of Elsevier

store.elsevier.com

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Morris
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Second Edition

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AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Academic Press is an imprint of Elsevier

Academic Press is an imprint of Elsevier
125 London Wall, London EC2Y 5AS, UK
525 B Street, Suite 1800, San Diego, CA 92101-4495, USA
225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK

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ISBN: 978-0-12-800884-3

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

Publisher: Joe Hayton
Acquisition Editor: Steve Merken
Editorial Project Manager: Nate McFadden
Production Project Manager: Nicky Carter
Designer: Matthew Limbert

Typeset by TNQ Books and Journals
www.tnq.co.in

Printed and bound in the United States of America

Measurement and Instrumentation

Preface

The foundations of this book lie in the highly successful text, *Principles of Measurement and Instrumentation* by Alan Morris. The first edition of this was published in 1988, and a second, revised and extended edition appeared in 1993. This was followed, in 2001, by a text with further revisions to the content and a new title, *Measurement and Instrumentation Principles*.

The first edition of this current text then followed in 2011. In developing this, the opportunity was taken to strengthen the book by bringing in a second author, Professor Reza Langari of Texas A&M University, who has made significant contributions especially in the areas of data acquisition and signal processing and the implementation of these using industry-standard LabView software. As well as this new contribution by Professor Langari, this edition covered many new developments in the field of measurement. In particular, it covered the significant recent advances that have been in smart sensors, intelligent instruments, microsensors, data acquisition, digital signal processing, digital recorders, digital fieldbuses, and new methods of signal transmission. The rapid growth of digital components within measurement systems also created a need to establish procedures in the book for measuring and improving the reliability of the software that is used within such components. Formal standards governing instrument calibration procedures and measurement system performance were extended beyond the traditional area of quality assurance systems (ISO9000) into new areas such as environmental protection systems (ISO14000). Thus, when published in 2011, the book was reasonably up to date with all the recent developments in measurement systems up to that time.

One notable development in this latest edition is that there is a large increase in the amount of material on measurement uncertainty. This includes an extended discussion on induced measurement noise and the various sources of this, such as inductive coupling, capacitive (electrostatic) coupling, noise due to multiple earths, noise in the form of voltage transients, thermoelectric potentials, shot noise, and electrochemical potentials. There is also a significant increase in the number of worked examples. As a consequence, this expansion has necessitated splitting the previous single chapter on this topic into two chapters.

The past four years have also seen continual developments of new sensors, and especially microscale (MEMS) and nanoscale (NEMS) ones. These developments are covered in the chapter on sensor technologies and also in later chapters devoted to sensors for measuring particular physical variables. At the same time, the continued usage of devices built on older technologies has been reviewed, resulting in the exclusion of those that are now very uncommon. The number of end-of-chapter student problems has also been expanded significantly, as the process of solving such problems is felt to be a valuable aid in the learning process for students.

The overall aim of the book continues to be to present the topics of sensors and instrumentation, and their use within measurement systems, as an integrated and coherent subject. Measurement systems, and the instruments and sensors used within them, are of immense importance in a wide variety of domestic and industrial activities. The growth in the sophistication of instruments used in industry

has been particularly significant as advanced automation schemes have been developed. Similar developments have also been evident in military and medical applications.

Unfortunately, the crucial part that measurement plays in all of these systems tends to get overlooked, and measurement is therefore rarely given the importance that it deserves. For example, much effort goes into designing sophisticated automatic control systems, but little regard is given to the accuracy and quality of the raw measurement data those such systems use as their inputs. This disregard of measurement system quality and performance means that such control systems will never achieve their full potential, as it is very difficult to increase their performance beyond the quality of the raw measurement data on which they depend.

Ideally, the principles of good measurement and instrumentation practice should be taught throughout the duration of engineering courses, starting at an elementary level and moving on to more advanced topics as the course progresses. With this in mind, the material contained in this book is designed both to support introductory courses in measurement and instrumentation, and also to provide in-depth coverage of advanced topics for higher-level courses. In addition, besides its role as a student course text, it is also anticipated that the book will be useful to practising engineers, both to update their knowledge of the latest developments in measurement theory and practice, and also to serve as a guide to the typical characteristics and capabilities of the range of sensors and instruments that are currently in use.

Following the usual pattern with measurement textbooks, the early chapters deal with the principles and theory of measurement and then subsequent chapters cover the ranges of instruments and sensors that are available for measuring various physical quantities. This order of coverage has been chosen so that the general characteristics of measuring instruments, and their behavior in different operating environments, are well established before the reader is introduced to the procedures involved in choosing a measurement device for a particular application. This ensures that the reader will be properly equipped to appreciate and critically appraise the various merits and characteristics of different instruments when faced with the task of choosing a suitable instrument in any given situation.

It should be noted that, while measurement theory inevitably involves some mathematics, the mathematical content of the book has deliberately been kept to the minimum necessary for the reader to be able to design and build measurement systems that perform to a level commensurate with the needs of the automatic control scheme or other system that they support. Where mathematical procedures are necessary, worked examples are provided throughout the book to illustrate the principles involved. Self-assessment questions are also provided in critical chapters to enable readers to test their level of understanding.

The early chapters are organized such that all of the elements in a typical measurement system are presented in a logical order, starting with the capture of a measurement signal by a sensor and then proceeding through the stages of signal processing, sensor output transducing, signal transmission, and signal display or recording. Ancillary issues, such as calibration and measurement system reliability, are also covered. Discussion starts with a review of the different classes of instruments and sensors available, and the sort of applications in which these different types are typically used. This opening discussion includes analysis of the static and dynamic characteristics of instruments and exploration of how these affect instrument usage. A comprehensive discussion of measurement system errors then follows, with appropriate procedures for quantifying, analyzing, and reducing errors being presented across two chapters. The importance of calibration procedures in all aspects of measurement systems, and particularly to satisfy the requirements of standards such as ISO9000 and ISO14000, is recognized by devoting a full chapter to the issues involved. This is followed by a chapter explaining data acquisition techniques and discussing the various analog- and digital signal-processing procedures that are

used to attenuate noise and improve the quality of signals. Following this, the next chapter is devoted to presenting the range of variable conversion elements (transducers) and techniques that are used to convert non-electrical sensor outputs into electrical signals, with particular emphasis on electrical bridge circuits. The problems of signal transmission are considered in the next chapter, and various means of improving the quality of transmitted signals are presented. The following chapter then discusses the various indicating and test instruments that are used to display and record electrical measurement signals. This chapter also covers data presentation methods and related issues such as least-squares curve fitting, confidence tests, and correlation tests. The next consideration is the subject of intelligent devices and the related issues of digital computation techniques, input–output interfaces, data buses, data networks, and fieldbus technologies. The following chapter then discusses the issue of measurement system reliability, and the effect of unreliability on plant safety systems. This discussion also includes the subject of software reliability, since computational elements are now embedded in many measurement systems. The next chapter provides a comprehensive introduction to the features of the Labview software package. Various examples are provided in this chapter that explains the application of LabView to implement the data acquisition and digital signal processing techniques covered earlier in Chapter 6. Finally, this initial set of chapters covering measurement theory concludes with a chapter on the various sensor technologies that are in use. This coverage includes discussion on recently developed technologies and, particularly, the advances in micro-machines structures (MEMS and NEMS) devices.

Subsequent chapters then provide comprehensive coverage of the main types of sensors and instruments that exist for measuring all the physical quantities that a practicing engineer is likely to meet in normal situations. However, while the coverage is as comprehensive as possible, the distinction is emphasized between (1) instruments that are current and in common use, (2) instruments that are current but not widely used except in special applications, for reasons of cost or limited capabilities, and (3) instruments that are largely obsolete as regards new industrial implementations, but are still encountered on older plant that was installed some years ago. As well as emphasizing this distinction, some guidance is given about how to go about choosing an instrument for a particular measurement application and how to implement appropriate calibration techniques. It should be noted that the reader familiar with first edition will notice the exclusion of some devices previously included, as a result of their use being largely now discontinued.

Resources for instructors: A solution manual is available by registering at http://textbooks.elsevier.com/9780128008843.

Acknowledgement

The Author gratefully acknowledges permission by John Wiley and Sons, Ltd, to reproduce some material that was previously published in *Measurement and Calibration Requirements for Quality Assurance to ISO9000* by A S Morris (published 1997). The material involved is Tables 1.1, 1.2 and 3.1, figures 3.1, 5.2 and 5.3, parts of sections 2.1, 2.2, 2.3, 3.1, 3.2, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 5.3 and 5.4, and Appendix 1.

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