SERIES IN SENSORS

Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies

Winncy Y. Du

CRC Press
Taylor & Francis Group

Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20140919

International Standard Book Number-13: 978-1-4398-1244-0 (Hardback)

Library of Congress Cataloging-in-Publication Data

Du, Winncy.
Resistive, capacitive, inductive, and magnetic sensor technologies / author, Winncy Du.
pages cm. -- (Series in sensors)
Includes bibliographical references and index.
ISBN 978-1-4398-1244-0 (hardback)
1. Detectors. 2. Transducers. I. Title.

TK7872.D48D83 2014
681'.2--dc23 2013045996

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies

Series in Sensors

Series Editors: Barry Jones and Haiying Huang

Other recent books in the series:

Semiconductor X-Ray Detectors
B. G. Lowe and R. A. Sareen

Portable Biosensing of Food Toxicants and Environmental Pollutants
Edited by Dimitrios P. Nikolelis, Theodoros Varzakas, Arzum Erdem, and Georgia-Paraskevi Nikoleli

Optochemical Nanosensors
Edited by Andrea Cusano, Francisco J. Arregui, Michele Giordano, and Antonello Cutolo

Electrical Impedance: Principles, Measurement, and Applications
Luca Callegaro

Biosensors and Molecular Technologies for Cancer Diagnostics
Keith E. Herold and Avraham Rasooly

Compound Semiconductor Radiation Detectors
Alan Owens

Metal Oxide Nanostructures as Gas Sensing Devices
G. Eranna

Nanosensors: Physical, Chemical, and Biological
Vinod Kumar Khanna

Handbook of Magnetic Measurements
S. Tumanski

Structural Sensing, Health Monitoring, and Performance Evaluation
D. Huston

Chromatic Monitoring of Complex Conditions
Edited by G. R. Jones, A. G. Deakin, and J. W. Spencer

Principles of Electrical Measurement
S. Tumanski

Novel Sensors and Sensing
Roger G. Jackson

Hall Effect Devices, Second Edition
R. S. Popovic

Sensors and Their Applications XII
Edited by S. J. Prosser and E. Lewis

To my late parents: Xianmin Du (杜贤民) and Shujie Chao (曹淑杰)
who not only gave me life, but also taught me how to live;
To my dear brothers: Chengzhi Du (杜承志) and Yingzhi Du (杜英志)
who never ask me for anything, but always give me everything;
To my beloved husband: Scott Yelich
who enriches my life and multiplies my efforts.

Preface

Resistive, capacitive, inductive, and magnetic (RCIM) sensors comprise more than 70% of the sensor market today. For many years, there has been a strong need for a comprehensive book on RCIM sensors that combines the most important physical principles, designs, and practical applications of the RCIM sensors. This book was designed to fill that need. It is based on sensor information that the author has collected over the years, her research work, and lecture materials she has developed while teaching sensor technology-related courses with the Department of Mechanical Engineering at San Jose State University.

This book is a complete and comprehensive overview of RCIM sensing technologies. It contains six chapters beginning with RCIM sensor characteristics and terminology (Chapter 1), followed by resistive (Chapter 2), capacitive (Chapter 3), inductive (Chapter 4), and magnetic (Chapter 5) sensors. Sensor signal characteristics, noise types, bridge and compensation circuits, passive/active filters and signal conditioning are also covered (Chapter 6). The unique features of this book include: (1) *Completeness*: It covers all the dominating principles for RCIM sensors. For instance, on electromagnetic sensors alone (including inductive and magnetic sensors), more than 15 different physical laws, phenomena, and effects are presented. No other single book or review paper has such a complete coverage of inductive/magnetic sensing principles. (2) *Conciseness*: Many sensing principles involve abstruse theories and complex mathematical equations, some of which could fill an entire book. Here, each principle and its associated mathematical model and theory are described in a way that makes it easy for readers to follow and understand. In addition, many useful illustrations are provided to help readers visualize the material. (3) *Comprehensiveness*: Unlike some sensor books that are either too theoretical or too practical, this book provides a good balance. The mathematical equations have been chosen based on which equations have the most influence on the sensor's performance, whereas the practical examples have been selected based on which examples best represent a typical scenario or cover a new area of application. (4) *Practicality*: The calculation examples and exercise problems provided are realistic and represent real-world sensor data and performance. Each parameter value and every curve presented in the examples or exercise problems are from experiments performed by the author, published research papers, or manufacturers' testing data. This allows readers to learn theory along with the true levels of sensor performance.

The information provided in this book will not only help readers to understand RCIM sensors, but also to understand many other types of sensors quickly and efficiently since there are many overlaps in terms of principles, material characteristics, noise types, design considerations, sensor circuitry and signal conditioning. The book is interdisciplinary in nature and will be helpful in subjects or courses such as sensor technologies and principles, applied physics, semiconductor materials and applications, engineering design, mechatronics, robotics, automatic control using sensor feedback, nondestructive inspection (NDI) technologies, analog signal

processing, sensor circuitry, and instrumentation and measurements. This book is intended for advanced undergraduate and graduate-level engineering students. It would also be a useful reference for professional engineers at all levels and scientists involved in sensor research and development.

Winncy Y. Du
San Jose, California, USA

Acknowledgments

I would like to thank the students who pilot-tested this book in my sensor classes for their valuable feedback and working on the exercise problems; and the companies and publishers who allowed me to use their data, drawings, and materials. I am especially indebted to my husband, Scott Yelich, for his tireless proofreading of the book draft, his meticulous and thoughtful suggestions, and his support and encouragement during this challenging project. Last, but not the least, I would like to acknowledge the excellent services and support provided by the editorial and production staff at Taylor & Francis Group, LLC.

Winncy Y. Du
San Jose, California, USA

Author

Dr. Winncy Y. Du is a professor with the Department of Mechanical Engineering at *San Jose State University* (SJSU) where she is director of the Robotics, Sensor, and Machine Intelligence Laboratory. She is a visiting professor with the Department of Mechanical Engineering at MIT. Her PhD in mechanical engineering and MS degree in electrical and computer engineering were awarded by the *Georgia Institute of Technology*. She earned MS and BS degrees in mechanical engineering from *West Virginia University* and Jilin University (China), respectively. She also holds *Professional Engineer (PE), Engineer-in-Training (EIT)*, and *Computer Integrated Manufacturing Systems (CIMS)* licenses/certificates. Prior to joining SJSU, she was an assistant professor at *Georgia Southern University*. She also worked as a journal editor, engineer, and researcher with the *Science and Technology Research and Information Center, Ministry of Mechanical and Electronics Industry of China*. Her research and teaching areas are sensors, robotics, mechatronics, automation, and control, with an emphasis on health care and biomedical applications. She teaches a wide range of undergraduate and graduate courses, has published more than 40 peer-reviewed journal/conference papers, and contributed to the books *Smart Sensors and Sensing Technology* (Springer-Verlag, 2008) and *Modern Sensors, Transducers and Sensor Networks* (International Frequency Sensor Association, 2012). She is a principal investigator (PI) or co-PI of more than 10 research grants, and the leader of more than 20 industry sponsored research projects. In 2010, she was awarded the rank of Fellow with American Society of Mechanical Engineers in recognition of her exceptional engineering achievements and contribution to the engineering profession. She is also an active member of IEEE. Her professional honors include the International ASME Diversity & Outreach Award (2004), Richard A. Fitz Outstanding Faculty Advisor Award (2005), ASME District D Student Section Advisor Award (2007, 2011, and 2013), Charles W. Davidson College of Engineering Faculty Award for Excellence in Scholarship at SJSU (2012), and Newnan Brothers Award for Faculty Excellence (2014).

Contents