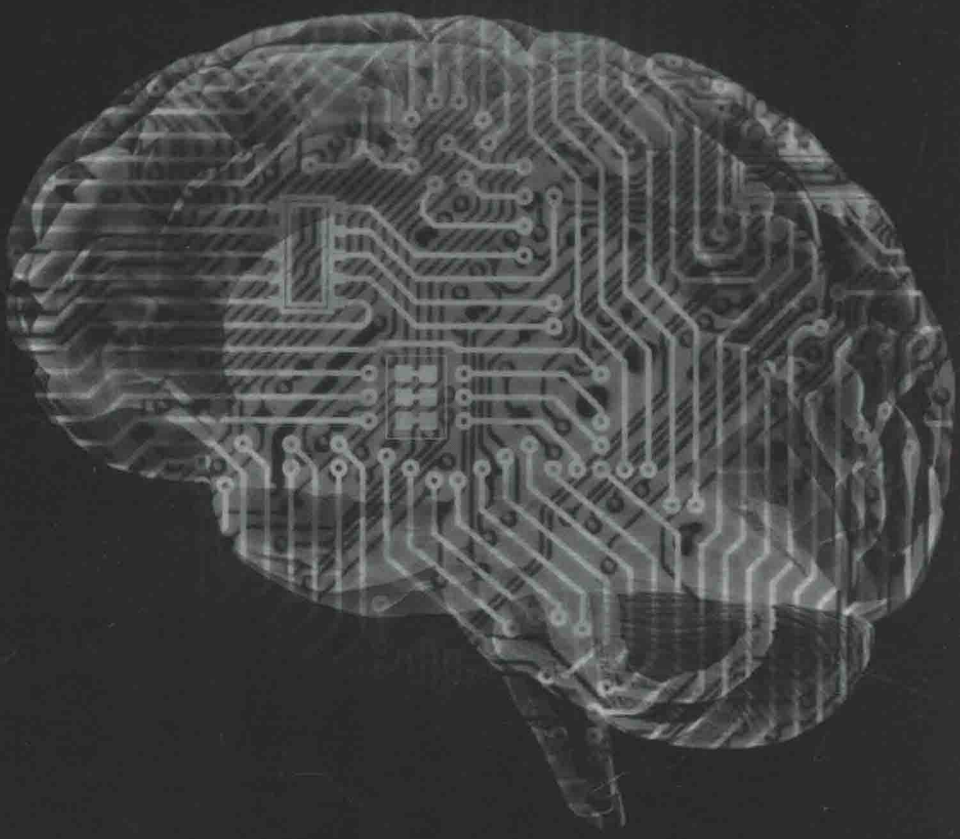
Intelligent Instrumentation

Principles and Applications



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INTELLIGENT INSTRUMENTATION

Principles and Applications

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God has blessed me with a wonderful family and a

wonderful teacher in Instrumentation

I dedicate this book to my wife Nanti, daughter Pahi, and son Pol, and

to

Prof. Manoj Kumar Ghosh, retired professor of IIT Kharagpur, India

Preface

Classical sensors have been traditionally used in various measurement and process control applications for a variety of parameters. A signal-conditioning circuit when interfaced to a sensor enhances the performance of the sensors manyfold. Signal-conditioning operations are very common in instrumentation systems and have been used since long in the field of measurement and process control applications. With the advent of microprocessors and digital-processing technologies, such signal conditioning operations have been developed rapidly and the technologies have been found to have a good rapport with instrumentation systems. Many such sensors with microprocessor-based signal-conditioning devices have attracted a high volume of consumers.

The applications of instrumentation and process control have grown rapidly requiring medium-to-extremely complicated measurement systems. During the last decade, many new types of process parameters have evolved requiring new technologies of sensor or signal-conditioning systems. While classical sensors target general types of measurement systems, the newer sensor technologies focus on more specialized process parameter measurements. In many situations, such a sensor has not only to measure a process parameter, but has also to take additional decisions and perform many other nonconventional operations such as validation, compensation, and classification. This new category of sensors carries the tag *intelligent* and has expanded the scope of incorporating *intelligence* to instrumentation systems.

Why Do We Need a Textbook on Intelligent Instrumentation?

Incorporation of intelligence to classical sensors has been done by researchers and sensor manufacturers in various ways. Based on the design approach of such sensors with added intelligent features, several varieties of intelligent sensors are modeled, implemented, and even marketed commercially. Due to the nonavailability of specific definitions, there is no straightforward indication in such innovations about the requisite features of an intelligent instrumentation system. Very often, a sensor integrated with a digital processor in a single chip is also termed an intelligent sensor, but it is not indicative of any intuitive ability of the sensor's functionality. There are many

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texts on intelligent sensors and instrumentation, but none of them define the technologies and services in a categorial manner. Moreover, many of the intelligent sensors developed so far are commercially viable due to the important services they offer, while many of them are not due to inappropriate design methodology.

Texts on intelligent instrumentation and intelligent sensors abound in various research articles and manufacturers' application notes; however, general texts on their design approaches are still far less than expected. *Intelligent Instrumentation: Principles and Applications* is designed as a textbook for a first course on intelligent instrumentation.

Why do we need a classroom course on intelligent instrumentation? Over the past decade or so, many universities have included topics on intelligent instrumentation in their courses on classical instrumentation. These topics mostly cover *integrated smart sensors* and the broad topics covering the entire family of intelligent instrumentation are found missing. Conventional instrumentation has rapidly shifted to intelligent instrumentation over the last decade. Researchers are continuously trying to add intelligence to sensors using state-of-the-art methodologies, but researching for a target service is different from understanding the underlying principles and design methodologies of intelligent instrumentation.

This author has taught conventional instrumentation with varying patterns of course structures for the last 30 years. Since five years or so, I have tried to cover some topics on 'intelligent instrumentation' in the classical instrumentation course. However, the students' confusion as to which book to follow motivated me to write a textbook on intelligent instrumentation covering the design methodologies and their relevant applications.

Who Will Benefit Most from This Book?

This textbook is not self-contained and neither does it try to be not to go too much beyond its scope. It is intended as a classroom course for engineering graduates and covers the theories and applications of intelligent instrumentation or an elective course. The contents of this book can also be spread over two semesters. Apart from its usefulness in the classroom, this book will also be useful for practicing engineers and manufacturers. Besides theory on intelligent instrumentation, it includes many applications as case studies and, hence, can also be useful for researchers. The readers would also need to take a course on instrumentation as a prerequisite for this book, though Chapters 1 and 2 do cover the basics of sensors, transducers, and their performance characteristics.

How Is This Book Different from Others?

The basic feature of this book is that it explains the underlying design methodologies of intelligent instrumentation for researchers and manufacturers in a textbook-like language, translates these methodologies to numerical examples, and provides applications in case studies. There are at least 80 solved numerical examples and 14 case studies in this book. The major features of this book are as follows:

1. **Prerequisite chapters**: To understand the design methodologies of intelligent instrumentation, readers need to be familiar with the concepts of sensor devices and their performance characteristics, and signals and system dynamics. Chapters 1 through 3 cover these topics.
2. **Design emphasis**: The basic design principles of intelligent sensors are emphasized in Chapters 4 and 6 and their applications are shown using numerical examples and case studies. This approach helps the students to use the principles in real-world problems.
3. **Intelligent processing**: Intelligent sensors rely on signal processing operations such as calibration, linearization, and compensation. Chapter 5 deals exclusively with intelligent signal processing operations and provides a wide range of numerical examples.
4. **Artificial intelligence**: Artificial intelligence is one of the major components of intelligent sensors. Use of artificial neural networks (ANNs) in sensor signal processing is very useful nowadays and can solve many real-world problems. A chapter is included to explain such issues (Chapter 6).
5. **Integral use of MATLAB®**: MATLAB programs have been provided throughout the book to validate the design approaches. MATLAB can be used not only to prove the design methods, but is also an essential tool for many signal preprocessing and statistical measurements.

Organization

Chapter 1 provides a brief introduction to the basic concepts of process, process parameters, sensors and transducers, and classification of transducers, with examples ranging from radio-isotopic sensors to biosensors. The aim of this chapter is to provide a review of classical sensors and transducers.

Although a basic course on instrumentation is a prerequisite for this book, this chapter will serve as a refresher course.

Chapter 2 deals with the performance characteristics of instrumentation and measurement systems that discuss the static and dynamic characteristics. Since the intelligent processing of sensors focuses on enhancing their performance, the topics covered in this chapter will be an essential component of the book.

Intelligent signal processing deals with various types of sensor signals and the readers must therefore understand the concepts of signal representations, various transforms, and their operations in both static and dynamic conditions. Chapter 3 intends to provide such an understanding and knowledge to the readers.

Intelligent sensors developed so far by various researchers use different technologies and provide different services. The nomenclature of intelligent sensors is a complex task since, in most cases, the technologies and services are overlapping. Chapter 4 provides a unified approach to classify the intelligent sensors with their underlying design principles. It describes smart sensors, cogent sensors, soft sensors, self-validating sensors, VLSI sensors, temperature-compensating sensors, microcontrollers and ANN-based sensors, and indirect measurement sensors.

While discussing intelligent sensors in Chapter 4, the basic signal conditioning techniques were not elaborately explained. Chapter 5 addresses the issues dealing with intelligent sensor signal conditioning such as calibration, linearization, and compensation. A wide variety of calibration and linearization techniques using circuits, analog-to-digital converters (ADCs), microcontrollers, ANNs, and software are discussed in this chapter. Compensation techniques such as offset compensation, error and drift compensation, and lead wire compensation are also discussed here.

Chapter 6 deals with intelligent sensors that rely on ANN techniques for pattern classification, recognition, prognostic diagnosis, fault detection, linearization, and calibration. The chapter begins with the basic concepts of artificial intelligence and then moves on to ANN applications.

Interfacing of intelligent sensors to the processor and the users is a major issue. In order to achieve higher efficiency, uniformity, and flexibility of intelligent sensors, various interfacing protocols have been developed either in wireless platforms or on the Internet. Chapter 7 discusses a few important interfacing protocols in the wireless networking platform.

At the end of every chapter, a reference list is included to aid the reader consult the original text wherever necessary. Questions and problems for practice are also provided in a separate chapter as Chapter 8.

An Advice to Course Instructors

This book covers topics more than are required for a semester. Course instructors may organize the topics in the following manner:

Option 1 (when the students have not taken a course on instrumentation)

Semester 1: Course—Introduction to intelligent sensors (Chapters 1 and 2, Sections 4.1 through 4.7)

Semester 2: Course—Signal processing for intelligent sensors (Sections 4.8 and 4.9, Chapter 5)

Option 2 (when the students have already taken a course on instrumentation)

Semester 1: Course—Intelligent instrumentation (Chapter 4, Sections 6.1 through 6.2.2)

Semester 2: Course—Signal processing for intelligent sensors (Chapter 5, Section 6.2.3)

Chapter 7 is a supporting chapter; course instructors may therefore include one or two topics from this chapter depending on the requirement.

As a final word, the applications described in the case studies may be referred to by researchers for designing their sensors for a particular application.

Suggestions, feedback, and comments from course instructors, students, and other readers are welcome for the improvement of this book.

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Dr. Manabendra Bhuyan is a professor of electronics and communication engineering at Tezpur (Central) University, India. He has been teaching instrumentation for more than 30 years. Currently, his teaching and research areas include instrumentation, sensor signal processing, intelligent systems, and biomedical signal processing. He has authored more than 50 research publications in various journals and conferences and holds 2 patents. He has authored a book, *Measurement and Control in Food Processing*, published by Taylor & Francis, Boca Raton, Florida, and has contributed chapters to several books. Professor Bhuyan received his BE from Dibrugarh University, India; his MTech from the Indian Institute of Technology, Kharagpur, India; and his PhD from Gauhati University, India.

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