SENSORS AND SIGNAL CONDITIONING

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Second Edition

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PREFACE

Sensors have been traditionally used for industrial process control, measurement, and automation, often involving temperature, pressure, flow, and level measurement. Nowadays, sensors enable a myriad of applications fostered by developments in digital electronics and involving the measurement of several physical and chemical quantities in automobiles, aircraft, medical products, office machines, personal computers, consumer electronics, home appliances, and pollution control.

Many of the new application areas for sensors do not pose any severe working conditions and are high-volume consumers. This makes those applications a target for semiconductor-based sensors, particularly sensors built by microfabrication techniques (microsensors), which can be manufactured in large scale. Annual sales of accelerometers and pressure sensors in the automotive industry, along with the annual sales of blood pressure sensors in the medical industry, amount to tens of millions units. Gas sensors, rate sensors, CMOS image sensors, and biosensors can similarly boom.

Classical sensors (or macrosensors) have not been superseded by the new microsensors. Many conventional sensors are still required for specialized applications, so there is no replacement for them in the foreseeable future. Nevertheless, the performance of several integrated circuits commonly used in signal conditioning has improved and allows the design of simpler circuits. Also, there are specific integrated circuits intended for conditioning the signals of common sensors such as thermocouples, RTDs, capacitive sensors, and LVDTs, and microcontrollers have become an inexpensive resource for low-cost, low-resolution analog-to-digital interfacing. Furthermore, the low cost of digital computing has moved part of the calculations and compensations closer to the sensor. The communication with a central controller is increasingly digital, and intelligent (or smart) sensors are being installed in new factories.

This second edition responds to this new scenario from the same point of view of the first edition: that of electronic engineering students or professionals interested in designing measurement systems using available sensors and integrated circuits. For each sensor we describe the working principle, advantages, limitations, types, equivalent circuit, and relevant applications. To clarify sensor types and materials, there is a new section on sensor materials and another on microsensor technology. Microsensors available for different applications are mentioned in the corresponding sections. Sensors are grouped depending on whether (a) they are variable resistors, inductors, capacitors, (b) they generate voltage, charge, or current, or (c) they are digital, semiconductor-junction based, or use some form of radiation. This approach simplifies the study of signal conditioners, which are instrumental in embedding sensors in any electronic system. Basic measurement methods and primary sensors for common physical quantities are described in an expanded section. Further information can be found in J. G. Webster (ed.), *The Measurement, Instrumentation, and Sensors Handbook*, CRC Press, 1999.

Some new sensors covered are giant magnetoresistive sensors, resistive gas sensors, liquid conductivity sensors, magnetostrictive sensors, SQUIDs, fluxgate magnetometers, Wiegand and pulse-wire sensors, position-sensitive detectors (PSDs), semiconductor-junction nuclear radiation detectors, CMOS image sensors, and biosensors. Several of these have moved from the research stage to the commercialization stage since the publication of the first edition. Velocity sensors, fiber-optic sensors, and chemical sensors, in general, receive expanded coverage because of their wider use.

Signal conditioners use new ICs with improved parameters, which often enable novel approaches to circuit design. Some new topics are error analysis of single-ended amplifiers, current feedback amplifiers, composite amplifiers, and IC current integrators. The section on noise now includes noise fundamentals, noise analysis of transimpedance and charge amplifiers, and noise and drift in resistors. Chapter 8, on digital and intelligent sensors, has been expanded by adding sections on variable oscillators including a sensor, direct microcomputer interfacing, sensor communications, and intelligent sensors.

Because the selection of the sensor influences the sensitivity, accuracy, and stability of the measurement system, we describe a broad range of sensors and list the actual specifications of several commercial sensors in tables elsewhere in the book. We have summarized several relevant specifications of common integrated circuits for signal conditioning in tables. New sections deal with basic statistical analysis of measurement results, and reliability. We give 68 worked-out examples and include a total of 103 end-of-chapter problems, many from actual design cases. The annotated solution to the problems is in an appendix at the end of the book. End-of-chapter references have been updated. For ease of reference, figures for examples or problems are respectively preceded by an E or a P. Line crossings in figures are not a connection, unless indicated by a dot.

In the study of any field, the knowledge of important dates adds perspective. Hence, this book names the discoverer and approximate date of the discovery of different physical laws applied in sensors. This may also help in preventing professionals from thinking that sensors are subsequent to the transistor (1947), the operational amplifier (1963), or the microprocessor (1971). Some sensors existed long before all of them. It is the work of electronic engineers to apply all the capabilities of integrated circuits in order that the information provided by sensors results in more economical, reliable, and efficient systems for the benefit of the humans, who certainly have limited perception but who have unmatched intelligence and creativity.

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