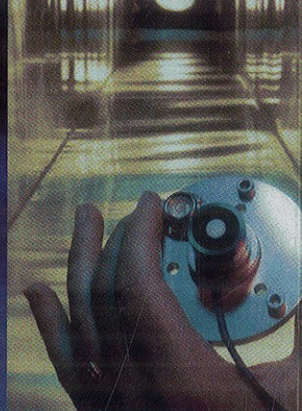


# Sensors Handbook

Second Edition ■

SABRIE SOLOMAN



# CONTENTS

**Foreword** xxiii

**Preface** xxv

**Acknowledgments** xxxvii

## **Introduction**

**1**

Establishing an Automation Program / 2

Understanding Flexible Workstations, Flexible Work Cells, and Flexible Work Centers / 3

## **Chapter 1. Types and Classifications of Sensors and Control Systems**

**9**

Classification of Control Processes / 9

Open- and Closed-Loop Control Systems / 9

Understanding Photoelectric Sensors / 12

Detection Methods / 18

Proximity Sensors / 21

Understanding Inductive Proximity Sensors / 23

Understanding Capacitive Proximity Sensors / 32

Understanding Limit Switches / 36

Inductive and Capacitive Sensors in Manufacturing / 36

Understanding Microwave-Sensing Applications / 51

The Infrared Spectrum: Understanding an Infrared Spectrum and How It Arises from Bond Vibrations Within Organic Molecules / 61

Understanding Laser Sensors / 63

References / 78

## **Chapter 2. Fiber Optics in Sensors and Control Systems**

**79**

Introduction / 79

Photoelectric Sensors—Long-Distance Detection / 79

Fiber Optics / 86

Optical Fiber Parameters / 90

Inductive Proximity Sensors—Noncontact Metal Detection / 92

Limit Switches—Traditional Reliability / 94

Factors Affecting the Selection of Position Sensors / 94

Wavelengths of Commonly Used Light-Emitting Diodes / 95

Sensor Alignment Techniques / 95

Fiber Optics in Industrial Communication and Control / 98

Principles of Fiber Optics in Communications / 98

Fiber-Optic Information Link / 99

Configurations of Fiber Optics	/ 100
Configurations of Fiber Optics for Sensors	/ 106
Flexibility of Fiber Optics	/ 110
Testing of Fiber Optics	/ 112
Networking with Electro-Optic Links	/ 118
Versatility of Fiber Optics in Industrial Applications	/ 123
References	/ 127

### **Chapter 3. Networking of Sensors and Control Systems in Manufacturing**

129

Introduction	/ 129
Number of Products in a Flexible System	/ 130
Sensors Tracking the Mean Time Between Operator Interventions	/ 131
Sensors Tracking the Mean Time of Intervention	/ 131
Sensors Tracking Yield	/ 131
Sensors Tracking the Mean Processing Time	/ 131
Network of Sensors Detecting Machinery Faults	/ 133
Understanding Computer Communications and Sensors' Role	/ 142
Understanding Networks in Manufacturing	/ 146
Manufacturing Automation Protocol	/ 150
Multiple-Ring Digital Communication Network—AbNET	/ 154
Universal Memory Network	/ 155
References	/ 157

### **Chapter 4. The Role of Sensors and Control Technology in Computer-Integrated Manufacturing**

159

Introduction	/ 159
CIM Plan	/ 159
Manufacturing Enterprise Model	/ 161
Design of CIM with Sensors and Control Systems	/ 172
Decision Support System for CIM with Sensors and Control Systems	/ 176
Analysis and Design of CIM with Sensors and Control Systems	/ 178
Data Acquisition for Sensors and Control Systems in CIM Environment	/ 180
Developing CIM Strategy with Emphasis on Sensors' Role in Manufacturing	/ 185
References	/ 194

### **Chapter 5. Advanced Sensor Technology in Precision Manufacturing Applications**

195

Identification of Manufactured Components	/ 195
Digital Encoder Sensors	/ 198
Fuzzy Logic for Optoelectronic Color Sensors in Manufacturing	/ 201
Sensors Detecting Faults in Dynamic Machine Parts (Bearings)	/ 208
Sensors for Vibration Measurement of a Structure	/ 210
Optoelectronic Sensor Tracking Targets on a Structure	/ 212
Optoelectronic Feedback Signals for Servomotors Through Fiber Optics	/ 213
Acoustooptical/Electronic Sensor for Synthetic-Aperture Radar Utilizing Vision Technology	/ 215
The Use of Optoelectronic/Vision Associative Memory for High-Precision Image Display and Measurement	/ 216



Sensors for Hand-Eye Coordination of Microrobotic Motion Utilizing Vision Technology /	217
Force and Optical Sensors Controlling Robotic Gripper for Agriculture and Manufacturing Applications /	219
Ultrasonic Stress Sensor Measuring Dynamic Changes in Materials /	220
Predictive Monitoring Sensors Serving Cim Strategy /	221
Reflective Strip Imaging Camera Sensor—Measuring a 180°-Wide Angle /	223
Optical Sensor Quantifying Acidity of Solutions /	224
Sensors for Biomedical Technology /	225
References /	228

## **Chapter 6. Industrial Sensors and Control**

**231**

Introduction /	231
Sensors in Manufacturing /	233
Temperature Sensors in Process Control /	234
Pressure Sensors /	239
Fiber-Optic Pressure Sensors /	241
Displacement Sensors for Robotic Applications /	242
Process Control Sensors Measuring and Monitoring Liquid Flow /	244
Crack Detection Sensors for Commercial, Military, and Space Industry Use /	251
Control of Input/Output Speed of Continuous Web Fabrication Using Laser Doppler Velocity Sensor /	252
Ultrasonic/Laser Nondestructive Evaluation Sensor /	253
Process Control Sensor for Acceleration /	254
An Endoscope as Image Transmission Sensor /	255
Sensor Network Architecture in Manufacturing /	256
Power Line Fault-Detection System for Power Generation and Distribution Industry /	258
References /	259

## **Chapter 7. Sensors in Flexible Manufacturing Systems**

**261**

Introduction /	261
The Role of Sensors in FMS /	261
Robot Control Through Vision Sensors /	264
Robot Vision Locating Position /	268
Robot Guidance with Vision System /	268
End Effector Camera Sensor for Edge Detection and Extraction /	271
End Effector Camera Sensor Detecting Partially Visible Objects /	274
Ultrasonic End Effectors /	278
End Effector Sound-Vision Recognition Sensors /	280
End Effector Linear Variable-Displacement Transformer Sensors /	285
Robot Control Through Sensors /	289
Multisensor-Controlled Robot Assembly /	289
References /	296

## **Chapter 8. Communications**

**299**

Introduction /	299
Single-Board Computer /	299
Sensors for Input Control /	300
Microcomputer Interactive Development System /	302

Personal Computer as a Single-Board Computer /	304
The NC Controller /	308
Industrial Handling /	325
Packaging Technology /	328
Linear Indexing for Manufacturing Applications /	329
Synchronous Indexing for Manufacturing Applications /	333
Parallel Data Transmission /	334
Serial Data Transmission /	335
Collection and Generation of Process Signals in Decentralized Manufacturing Systems /	337
References /	340

---

## **Chapter 9. MEMS Applications in Energy Management**

---

343

Introduction /	343
Toward Improved Efficiency /	343
The Role of MEMS in Improved Efficiency /	343
A Low-Pressure Solution /	347
Summary /	351
References /	351

---

## **Chapter 10. The NANO/MEMS Program**

---

353

Introduction /	353
Nano/MEMS Sensor Programs /	353
Mems Sensors in Space Test Program Satellite /	361
Bulk Micromachined Accelerometers /	380
Surface Micromachined Microspectrometers /	386
References /	391

---

## **Chapter 11. MEMS in the Medical Industry**

---

393

Introduction /	393
History /	393
Current Uses for MEMS Devices in the Medical Industry /	395
Future Applications /	396
Hurdles/Enablers /	401
References /	403

---

## **Chapter 12. MEMS: Current and Future Technology?**

---

405

Introduction /	405
MEMS: A Current or Future Technology? /	405
What Are the Obstacles? /	407
References /	408

---

## **Chapter 13. MEMS Advanced Research and Development**

---

409

Introduction /	409
Nerve Grafting Materials /	420
CMOS Compatible Surface Micromachining /	424

Microinstrumentation /	425
Biomedical Applications /	425
Stanford CIS and the National Nanofabrication Users Network /	426
Summary /	426
Reference /	426

## **Chapter 14. Functional Integration of Microsystems in Silicon**

429

Introduction /	429
The Challenge /	429
The Appeal of on-Chip Integration /	430
The Technical Problems and the Economic Limitations /	430
Wafer Bonding as a Compromise /	433
The Multichip Module on Silicon as the Optimum Solution /	434

## **Chapter 15. Automotive Applications of Microelectromechanical Systems (MEMS)**

437

Introduction /	437
High Intensity of Light Emission /	439
Automotive Requirements /	441
Unique MEMS Features /	442
System Applications /	442
Market Figures /	450
References /	451

## **Chapter 16. A Brief Study of Magnetism and Magnetic Sensors**

453

Introduction /	453
The SI and Gaussian Units /	453
Field Sources /	455
AC Fields and DC Fields /	459
Magnetometers and Applications /	460

## **Chapter 17. The Fundamentals and Value of Infrared Thermometry**

463

Introduction /	463
Fundamentals of Infrared Thermometry /	465
The Selection Process /	469
Evaluating Infrared Thermometry /	471
References /	474

## **Chapter 18. GMR: The Next Generation of Magnetic Field Sensors**

475

Introduction /	475
GMR Materials /	475
GMR Sensor Elements /	481
Integrated GMR Sensor /	484
Potential of GMR Sensor Technology /	488
References /	489

---

**Chapter 19. Smart Civil Structures, Intelligent Structural Systems** 491

---

Introduction / 491  
Smart Structures? / 492  
Fiber-Optic Sensing / 492  
A Few Fiber Optics Smart Structure Results / 493  
References / 494

---

**Chapter 20. True Online Color Sensing and Recognition** 497

---

Introduction / 497  
Sensing Light and Color / 497  
The Definition of Color / 497  
Light/Energy Spectrum Distribution / 498  
Light Distribution / 499  
Metamerism / 502  
Background / 502  
System Description / 502  
Advantages of Online Color Sensors / 502  
Color Theory / 503  
Principles of Operation / 503  
Examples of Applications / 504

---

**Chapter 21. Fundamentals of Solid-State Presence-Sensing Technologies** 505

---

Presence Detection / 505  
Presence Sensors / 505  
Magnetic-Actuated Switch Applications / 508  
Components of a Solid-State Sensor / 510  
Inductive Principles / 512  
Shielded and Nonshielded Inductive Sensors / 512  
Capacitive Principles / 512  
General Photoelectric Terminology / 513  
Fiber-Optic Sensors / 519  
Solid-State Sensor Technologies / 521  
Transistor Switching for DC / 523  
Three-Wire Technology / 524  
Two-Wire Technology / 525  
Radio Frequency Immunity / 527  
Weld Field Immunity / 528  
Response Time: Inertia / 528  
Response Time / 530  
Standard Operating Frequency / 531

---

**Chapter 22. Design and Application of Robust Instrumentation Sensors in Extreme Environments** 533

---

Introduction / 533  
Design Challenges / 536  
Extreme Environmental Conditions / 536  
Power Disturbances / 537  
Electromagnetic Interference / 538  
Lightning and Static Discharge / 539

Reliability and Maintenance /	539
Case Histories /	540

## **Chapter 23. Color Machine Vision**

543

Why Color Vision? /	543
Principles of Color Sensing and Vision /	544
Lighting for Machine Vision /	547
Color CCD Cameras /	547
Traditional Color-Based Classification /	548
Apples and Oranges: A Classification Challenge /	550
Minimum Description: Classification by Distribution Matching /	552
Typical Industrial Applications /	554
References /	555

## **Chapter 24. Monolithic Integrated Physical and Chemical Sensors in CMOS Technology**

557

Introduction /	557
Physical Sensors /	558
Chemical and Biochemical Sensors /	563
References /	569

## **Chapter 25. A Research Prototype of a Networked Smart Sensor System**

571

Introduction /	571
Background /	571
Overview of Distributed Measurements /	572
Prototype System /	575
Interface Definitions /	579
Experience Using the Prototype System /	580
Topics for Future Research /	581
Appendix: Detailed Description of System Models /	582
References /	587

## **Chapter 26. Sensors and Transmitters Powered by Fiber Optics**

589

Introduction /	589
Fiber-Optic Power Interface /	590
Advantages of Fiber-Optic Power /	591
Practical Considerations of Fiber-Optic Power /	592
System Configurations and Applications /	593
References /	593

## **Chapter 27. A Process for Selecting a Commercial Sensor Actuator Bus as an Industry Interoperable Standard**

595

Introduction /	595
Background and Related Work /	596
The Process of Evaluation and Selection /	598
Sensor/Actuator Bus Survey /	600



Selection Criteria /	601
Candidate Presentation and Review /	605
SAB Interoperability Standard Selection /	606
Appendix: Listing of Acronyms /	607
References /	608

---

## **Chapter 28. A Portable Object-Oriented Environment Model (POEM) for Smart Sensors**

**611**

---

Introduction /	611
An Illustrative Example of OO Technology for Smart Sensors /	616
The Object Model in Detail /	617
Programming Support /	620
The Example Revisited /	623
Related Work /	626
References /	627

---

## **Chapter 29. New Generation of High-Temperature Fiber-Optic Pressure Sensors**

**629**

---

Introduction /	629
Sensor System Descriptions /	630
Sensor Head Design /	631
Autoreferencing Technique /	632
Sensor Calibration and Laboratory Tests /	633
Engine Test Results /	634
References /	636

---

## **Chapter 30. Principles and Applications of Acoustic Sensors Used for Gas Temperature and Flow Measurement**

**637**

---

Introduction /	637
Historical Review of Temperature and Flow Measurements /	637
High-Temperature Gas Measurements /	641
Acoustic Pyrometers /	647
The Measurement of Gas Flow in Large Ducts and Stacks /	653
Instruments Used to Measure Gas Flow in Ducts and Stacks /	655
References /	665

---

## **Chapter 31. Understanding and Applying Intrinsic Safety**

**669**

---

Introduction /	669
Where Can Intrinsic Safety Be Used? /	669
Methods to Prevent Explosions /	670
Limiting the Energy to the Hazardous Area /	670
Which Sensors and Instruments Can Be Made Intrinsically Safe? /	672
Make Sure the Circuit Works /	673
Barrier Types /	673
Rated Voltage /	674
Internal Resistance /	675

---

**Chapter 32. Application of Acoustic, Strain, and Optical Sensors to NDE of Steel Highway Bridges** 677

---

Introduction / 677  
Acoustic Emission Testing / 682  
Strain Gage Testing / 683  
Laser Displacement Gage Testing / 684  
Summary and Conclusions / 684

---

**Chapter 33. Long-Term Monitoring of Bridge Pier Integrity with Time Domain Reflectometry Cables** 687

---

Introduction / 687  
Background / 688  
TDR Cable Installation in New Column Construction / 690  
TDR Cable Installation in Existing Columns / 693  
References / 696

---

**Chapter 34. Sensors and Instrumentation for the Detection and Measurement of Humidity** 697

---

Introduction / 697  
The Definition of Humidity / 697  
Sensor Types / 698  
Summary of Balancing Methods / 716  
Other Types of Dew Point Hygrometers / 717  
Calibration / 720  
Applications / 723

---

**Chapter 35. Thermal Imaging for Manufacturing Process and Quality Control** 727

---

Introduction / 727  
Cameras / 727  
Processors / 729  
System Development / 730  
Summary / 731

---

**Chapter 36. The Detection of ppb Levels of Hydrazine Using Fluorescence and Chemiluminescence Techniques** 733

---

Introduction / 733  
The Experiment / 734  
References / 743

---

**Chapter 37. Molecular Relaxation Rate Spectrometer Detection Theory** 745

---

Introduction / 745  
References / 760

---

**Chapter 38. Current State of the Art in Hydrazine Sensing** **761**


---

Introduction	/ 761
Hydrazine Detection Infrared Spectrometers	/ 762
Electrochemical Sensors	/ 762
Colorimetric Detectors	/ 762
Colorimetric Dosimetry	/ 763
Ion Mobility Spectrometry	/ 764
Hydrazine Area Monitors	/ 765
Fluorescence Detection	/ 765
Conductive Polymer Hydrazine Sensors	/ 766
References	/ 766

---

**Chapter 39. Microfabricated Sensors: Taking Blood Testing Out of the Laboratory** **769**


---

Introduction	/ 769
Developing Arsenite Bacterial Biosensors	/ 778
Genome Manufacturing Proteome	/ 799
Biosensors for Automated Immunoanalysis	/ 803
References	/ 804

---

**Chapter 40. Closed-Loop Control of Flow Rate for Dry Bulk Solids** **807**


---

Introduction	/ 807
3D Force Sensing Tensile Tests of Coronary Stent	/ 812
A New Sensing Tool for Decoding the Genome	/ 820
The Structure and Nature of Closed-Loop Controls	/ 829
Weigh Belt Feeders and Their Flow Rate Control Loops	/ 831
Loss-in-Weight Feeder and Its Flow Rate Control Loop	/ 833
References	/ 833

---

**Chapter 41. Weigh Belt Feeders and Scales: The Gravimetric Weigh Belt Feeder** **835**


---

Introduction	/ 835
The Basics	/ 835
Principles of Weigh Belt Feeder Operation	/ 839
Applications of Weigh Belt Feeders	/ 854
Multi-Ingredient Proportioning for Dry Bulk Solids	/ 864
References	/ 866

---

**Chapter 42. Low-Cost Infrared Spin Gyro for Car Navigation and Display Cursor Control Applications** **867**


---

Introduction	/ 867
Theory of Operation	/ 867
Cursor Control Applications	/ 868
Car Navigation Applications	/ 869
The Effect of the Pendulum on Performance	/ 869
Software Compensation	/ 870
Navigation System Configuration	/ 871

Road Test Results /	872
Conclusion /	872

---

<b>Chapter 43. Quartz Rotation Rate Sensor: Theory of Operation, Construction, and Applications</b>	<b>873</b>
---	------------

---

Theory of Operation /	873
Construction /	875
Applications /	875

---

<b>Chapter 44. Fiber-Optic Rate Gyro for Land Navigation and Platform Stabilization</b>	<b>881</b>
---	------------

---

Introduction /	881
Gyro Design /	881
Performance /	884
References /	887

---

<b>Chapter 45. Composite Sensor Optics in Advanced Astronomical Observatories</b>	<b>889</b>
---	------------

---

Micromachined Sensing Technologies /	892
Acceleration Sensors /	893
Angular Rate Gyroscope /	894
Circuit Technology /	895
Low-G Accelerometer Applications /	897
Angular Rate Gyroscope Applications /	899
References /	900

---

<b>Chapter 46. Microfabricated Solid-State Secondary Batteries for Microsensors</b>	<b>901</b>
---	------------

---

Introduction /	901
Using Led Digital Cameras—Mobile Phones /	901
Experimental /	903
Results /	904
References /	912

---

<b>Chapter 47. High-Temperature Ceramic Sensors</b>	<b>913</b>
---	------------

---

Introduction /	913
Ceramic Gas Sensors /	914
Ceramic Thermistors /	918
References /	921

---

<b>Chapter 48. Microfabricated and Micromachined Chemical and Gas Sensor Developments</b>	<b>923</b>
---	------------

---

Introduction /	923
Tin Oxide-Based Sensors /	924

Schottky Diode-Type Sensors /	924
Solid Electrolyte Electrochemical Sensors /	925
Calorimetric Sensors /	926
References /	927

---

<b>Chapter 49. Electro-Formed Thin-Film Silica Devices as Oxygen Sensors</b>	<b>929</b>
--	------------

---

Introduction /	929
Device Preparation /	929
Precursor Chemistry /	930
Device Structure /	930
Sensor Operation /	934
Thin-Film Technologies in Sensor Manufacturing /	935
Summary /	939
References /	939

---

<b>Chapter 50. Using Leg-Mounted Bolt-on Strain Sensors to Turn Your Tank Into a Load Cell</b>	<b>941</b>
--	------------

---

Introduction /	941
Bolt-on Weight Sensing /	942
Bolt-on Weight Sensors vs. Load Cells /	943
Vessel Leg and Brace Temperature-Induced Stresses and the Cure /	945
Load Cells Using Microcell Strain Sensors /	946
Calibration Without Moving Premeasured Live Material /	947
References /	948

---

<b>Chapter 51. Five New Technologies for Weight Sensing Instrumentation</b>	<b>949</b>
---	------------

---

Introduction /	949
Sigma Delta A/D Conversion /	949
Dynamic Digital Filtering /	950
Multichannel Synchronous A/D Control /	952
Expert System Diagnostics /	953
Digital Communication Networks /	954
References /	956

---

<b>Chapter 52. Multielement Microelectrode Array Sensors and Compact Instrumentation Development at Lawrence Livermore National Laboratory</b>	<b>957</b>
--	------------

---

Introduction /	957
The Use of Microelectrodes in Sensor Development /	957
Powering Radio Sensors by Environmentally Safe Ambient Energy /	961
Requirements for Radio Technology and Energy Management /	965
References /	971

## **Chapter 53. Enabling Technologies for Low-Cost High-Volume Pressure Sensors**

973

Introduction / 973  
 Medical Disposable Pressure Sensors / 973  
 Miniature Pressure Sensors / 977  
 Smart Sensor Technology / 980  
 Sensor Communication / 982  
 References / 983

## **Chapter 54. A Two-Chip Approach to Smart Sensing**

985

Background / 985  
 Approaches to Solving Problems / 985  
 Product Examples / 987

## **Chapter 55. Specifying and Selecting Semiconductor Pressure Transducers**

989

General Factors / 989

## **Chapter 56. Introduction to Silicon Sensor Terminology**

997

Introduction / 997  
 General Definitions / 997  
 Performance-Related Definitions / 1001

## **Chapter 57. Silicon Sensors and Microstructures: Integrating an Interdisciplinary Body of Material on Silicon Sensors**

1007

Introduction / 1007  
 Markets and Applications / 1008  
 Generic Sensor Classification / 1009  
 Silicon Micromechanics: Advantages and Obstacles / 1018  
 Sensor Market Definitions / 1024  
 The World's Market Size and Growth / 1025  
 Characterization of Emerging Markets / 1028  
 Technology Trends / 1035  
 Market Trends / 1037  
 References / 1039

## **Chapter 58. Understanding Silicon Processing and Micromachining**

1041

What Is Silicon? / 1041  
 Basic Sensor Materials and Processing Techniques / 1045  
 Basic Pressure Sensor Process / 1051  
 References / 1054

**Chapter 59. Universal Sensors Technology: Basic Characteristics of Silicon Pressure Sensors****1057**

Silicon Piezoresistive Pressure Sensors / 1057  
Silicon Capacitive Pressure Sensors / 1082  
Silicon Accelerometers / 1084  
References / 1086

**Chapter 60. Advanced Sensor Designs****1087**

Introduction / 1087  
Fully on-Chip Compensated, Calibrated Pressure Sensors / 1087  
Pressure Sensors Using Si/Si Bonding / 1090  
Very Low Pressure Sensors / 1102  
References / 1104

**Chapter 61. Silicon Microstructures****1105**

Introduction / 1105  
Microplumbing / 1106  
Thermally Isolated Silicon Microstructures / 1110  
Electrical Switches / 1116  
Light Modulators and Deflectors / 1119  
Micromotors / 1120  
Resonant Structures for Measurement and Actuation / 1122  
Applications in Microbiology / 1122  
References / 1124

**Chapter 62. Computer Design Tools****1127**

Introduction / 1127  
Computer Modeling / 1128  
Process Modeling / 1134  
The Computer-Aided Layout of Sensors and Microstructures / 1135  
Electrical Modeling for Silicon Sensors / 1137

**Chapter 63. Signal Conditioning for Sensors****1141**

Introduction / 1141  
Characteristics of Pressure Sensors / 1142  
Constant Current vs. Constant Voltage Excitation / 1143  
Analog Electrical Models of Piezoresistive Pressure Sensors / 1144  
Basic Constant Current Compensation / 1152  
Constant Voltage FSO Compensation / 1160  
Gain Programming for Normalization / 1163  
Measurement of Differential Pressure Using Two Pressure Sensors / 1165  
Digital Compensation and Normalization / 1167  
Current Sources for Sensor Excitation / 1172  
Instrumentation Amplifiers / 1175  
Autozeroing Circuits with Eight-Bit Resolution / 1179  
Smart Sensors / 1181  
References / 1183



---

**Chapter 64. Advances in Surface Micromachined Force Sensors** **1185**


---

Introduction / 1185  
 Surface Micromachined Absolute Pressure Transducers / 1186  
 Resonant Integrated Microsensor (RIM) / 1188  
 References / 1190

---

**Chapter 65. Distributed, Intelligent I/O for Industrial Control and Data Acquisition: The Seriplex Sensor/Actuator Bus** **1193**


---

Introduction / 1193  
 System Description / 1196  
 How the System Works / 1199  
 ASIC General Description / 1199  
 Communication System—Master/Slave Mode / 1201  
 Communication System—Peer-to-Peer Mode / 1202  
 The CPU Interfaces / 1203  
 I/O Devices / 1209  
 Open Architecture / 1210

---

**Chapter 66. Innovative Solar Cell Mimics Photosynthesis** **1211**


---

Chromaticity—Color Rendering Index (CRI) / 1214  
 The LED Color Chart / 1217  
 The Color Rendering Index (CRI) / 1217  
 LEDs—Light-Emitting Diodes / 1219  
 The Basics on LEDs / 1225  
 Non-Phosphor White LEDs at a Viewing Angle of 30° / 1229  
 Luminous Intensity (Candlepower) / 1231  
 LED and Spectralon / 1238  
 Thin/Thick-Film Ceramics Sensors / 1239  
 The Thin-Film Process / 1240  
 The Thick-Film Process / 1240  
 Process for Electrode Contacts of Thin/Thick-Film Ceramic Sensors / 1242  
 Why Thin/Thick Films for Ceramic Sensors? / 1243  
 References / 1245

---

**Chapter 67. Quartz Resonator Fluid Monitors for Vehicle Applications** **1249**


---

Introduction / 1249  
 Quartz Resonator Sensors / 1250  
 Oscillator Electronics / 1256  
 Lubricating Oil Monitors / 1258  
 Battery State-of-Charge Monitors / 1261  
 Coolant Capacity Monitors / 1263  
 References / 1266

---

**Chapter 68. Overview of the Emerging Control and Communication Algorithms Suitable for Embedding in Smart Sensors** **1269**


---

Introduction / 1269  
 Generic Model of a Control System / 1270

Computers and Communication in Control	/ 1271
Plug-and-Play Communication Requirements	/ 1274
Modern Computation Techniques for Smart Sensors	/ 1275
Flexible Architecture for Smart Sensors	/ 1283
Remote Smart Sensors—Security Application	/ 1284
References	/ 1287

---

## **Chapter 69. Applications of Conductive Polymer-Based Chemical Sensors**

**1289**

---

Introduction	/ 1289
Experimental—Gold Interdigitated Electrodes	/ 1303
Results and Discussion	/ 1304
Summary	/ 1308
References	/ 1308

---

## **Chapter 70. Modeling Sensor Performance for Smart Transducers**

**1311**

---

Introduction	/ 1311
Compensating Sensor Errors	/ 1311
Statistical Compensation	/ 1313
Digital Compensation and Normalization	/ 1315
Conclusions	/ 1320
References	/ 1320

---

## **Chapter 71. Infrared Gas and Liquid Analyzers: A Review of Theory and Applications**

**1321**

---

Introduction	/ 1321
The Source	/ 1322
The Sample Cell	/ 1323
Sample Cell Window Materials	/ 1323
Optical Filters	/ 1324
Detectors	/ 1325
Applications	/ 1325

---

## **Chapter 72. Infrared Noncontact Temperature Measurement: An Overview**

**1327**

---

Introduction	/ 1327
Hardware Requirements	/ 1330
Target	/ 1330
Detectors	/ 1330
Optical Materials	/ 1331
Optical Filters	/ 1331
Two-Color Analysis	/ 1331
Applications	/ 1332

---

## **Chapter 73. Quality Control Considerations**

**1333**

---

Design Assurance	/ 1334
------------------	--------

**Chapter 74. Universal Drug and Food Cleanliness Using HPLC  
Sensing Detection** **1335**

---

**Chapter 75. Microsystem Technologies** **1341**

---

Introduction / 1341

Monolithic Magnetic Field-Sensor with Adaptive Offset Reduction / 1343

A Planar Fluxgate-Sensor with CMOS-Readout Circuitry / 1345

A Thermoelectric Infrared Radiation Sensor / 1347

Conclusion / 1348

References / 1348

**Index 1349**