

Measurement & Instrumentation

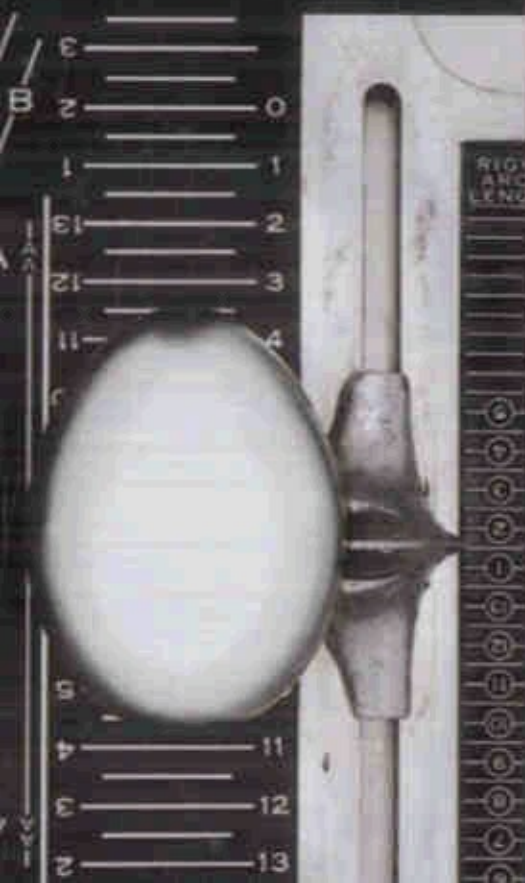
Trends & Applications

Edited by

M. K. Ghosh

S. Sen

S. Mukhopadhyay



CRC Press
Taylor & Francis Group

Contents

Preface

v

Part – A Introduction

1. Evolution and Trends in Measurement and Instrumentation 3-34

— *M. K. Ghosh*

<i>Abstract</i>	3
1.1 Evolution: Kelvinian Concept of Measurement	4
1.1.1 Instrumentation: Many Facets	7
1.1.2 Sensors: Techniques and Technology	8
1.1.3 Signal Conditioning and Signal Processing	19
1.1.4 Signal Transmission	21
1.1.5 End Devices and Interfacing	21
1.2 The Trends: Taking up New Challenges	22
1.2.1 Smart and Intelligent Sensors	22
1.2.2 Image Based Instrumentation	23
1.2.3 Multisensor Probe	25
1.2.4 Kelvinian Concept Revisited	25
1.2.4.1 Fuzzy Logic Based Measurement	27
1.2.4.2 Artificial Neural Network	27
1.2.4.3 Expert Systems	28
1.2.4.4 Concepts Based on Statistical Analysis	29
1.2.5 Virtual Instrumentation	30
1.3 The Monograph: Its Scope	31
1.4 References	32

2. Instrument Performance Evaluation 35-56

— *S. Sen*

<i>Abstract</i>	35
2.1 Static and Dynamic Characteristics	36
2.1.1 Static Characteristics	36
2.1.2 Dynamic Characteristics	38
2.1.3 Evaluation of Dynamic Performance	40
2.2 Deterministic and Stochastic Measurements	40
2.3 Error Analysis	41
2.3.1 Systematic Errors	42

2.4	Random Errors	42
2.4.1	Propagation of Errors	43
2.4.2	Normal (Gaussian) Distribution	45
2.4.3	Confidence Interval	46
2.4.4	Analysis with Finite Number of Samples	48
2.4.5	Chauvenet's Criterion	48
2.4.6	Importance of the Arithmetic Mean	49
2.4.7	Standard Deviation of the Mean	50
2.4.8	Confidence Interval for the Universal Mean	51
2.4.9	Student's <i>t</i> -distribution	51
2.5	Calibration and Error Reduction	53
2.6	References	55

Part – B

Sensors

3. Electrical Sensors	59-84
— <i>S. Sen</i>	
<i>Abstract</i>	59
3.1 Introduction	60
3.2 Active Sensors	61
3.2.1 Thermocouples	61
3.2.2 Piezoelectric Sensors	62
3.2.3 pH Sensors	62
3.3 Passive Sensors	64
3.3.1 Inductance Sensor	64
3.3.1.1 Variable Reluctance Type	64
3.3.1.2 Push-pull Variable Reluctance Sensors	66
3.3.1.3 Other Types of Reluctance Sensors	68
3.3.1.4 Linear Variable Differential Transformers (LVDT)	68
3.3.2 Capacitance Sensors	69
3.3.2.1 Capacitance Amplifier	72
3.3.2.2 Oscillator Sensor	74
3.3.2.3 Application Areas for Capacitance Sensors	75
3.3.2.4 Capacitance Microsensor	78
3.4 Mathematical Modeling of Sensors	79
3.4.1 Laplace Equation	79
3.4.2 Solution of Laplace Equation	81
3.5 References	84
4. Optical Sensors	85-130
— <i>M. K. Ghosh</i>	
<i>Abstract</i>	85
4.1 Introduction	86
4.1.1 Classification Based on Signal Acquisition Techniques	87
4.1.2 Classification Based on Coherency of Optical Sources	87

4.2	Sensors Based on Modulation of Optical Signal	88
4.2.1	Sensing with Air as Transmission Medium (nowaveguide)	88
4.2.2	Optical Sensors using Waveguides:	
	Optical Fibre Sensors (OFS)	97
4.3	Sensors Requiring Special Processing	111
4.3.1	Interferometry	111
4.3.2	Two Dimensional Optical Imaging	115
	4.3.2.1 Photography	116
	4.3.2.2 Videography	119
4.3.3	Imaging and Image Processing	119
4.3.4	Optical Fibre Imaging	119
4.3.5	Optical Signal Processing	120
4.3.6	Holography	122
	4.3.6.1 A Simple Mathematical Analysis	124
	4.3.6.2 Applications	125
4.4	Spectroscopy	125
4.4.1	UV Analyzer	125
4.4.2	IR Analyzer	126
4.4.3	Near IR Analyzer	127
4.4.4	Comparison of Absorption Spectrometers	127
4.5	Integrated Optics	128
4.6	References	129
5.	Chemical Sensors	131-156
	— <i>S. Basu, S. Roy</i>	
	<i>Abstract</i>	131
5.1	Introduction	132
5.2	Categories of Chemical Sensors	133
5.2.1	Chromatography and Spectrometry	133
	5.2.1.1 Bench-Top Gas Chromatographs (GC)	133
	5.2.1.2 Portable Gas Chromatographs	134
	5.2.1.3 Micro-Chem-Lab (μ ChemLab) on a Chip	134
	5.2.1.4 Ion Mobility Spectrometry	135
	5.2.1.5 Mass Spectrometry	136
5.2.2	Electrochemical Sensors	136
	5.2.2.1 Conductometric Sensors	136
	5.2.2.1.1 Polymer-Absorption Chemiresistors	137
	5.2.2.1.2 Catalytic Bead Sensors	139
	5.2.2.1.3 Metal-Oxide Semiconductor Sensors	140
	5.2.2.2 Potentiometric and Amperometric Sensors	145
5.2.3	Mass Sensors	148
	5.2.3.1 Surface Acoustic Wave Sensors/Portable	
	Acoustic Wave Sensors	148
	5.2.3.2 Microcantilever Sensors	150
5.2.4	Optical Sensor	151
	5.2.4.1 Fiber Optic Sensors	151

5.2.4.2	Calorimetry	152
5.2.4.3	Infrared Sensors	153
5.3	Conclusions	154
5.4	References	155
6.	Biochemical Sensors	157-178
	— <i>B. Adhikari</i>	
	<i>Abstract</i>	157
6.1	Introduction	158
6.1.1	Immobilization of Bioselective/Biospecific Component	159
6.1.2	Biocompatibility	160
6.1.3	Sterilization	160
6.1.4	Chemical Selectivity and Molecular Recognition	160
6.2	Measuring Principles in Biochemical Sensor Design	161
6.3	An Overview of Application	162
6.4	Some Selected Biochemical Sensors	168
6.5	Current Trends in Biochemical Sensor Research	170
6.6	References	174
7.	Nucleonic Sensors	179-194
	— <i>M. K. Ghosh</i>	
	<i>Abstract</i>	179
7.1	Introduction	180
7.2	Nucleonic Sources	180
7.3	Nucleonic Detectors	182
7.4	Signal Processing: The Measuring Circuits	185
7.5	Nucleonic Sensors	187
7.5.1	Sensing based on Ionisation	187
7.5.2	Sensing based on Intensity Modulation	187
7.6	Health Hazards and Protective Measures	192
7.7	References	193
8.	Microwave Sensors	195-226
	— <i>A. K. Mallick</i>	
	<i>Abstract</i>	195
8.1	Introduction	196
8.2	Basics of Microwave Propagation	197
8.2.1	Polarization and Modes	199
8.2.2	Antennas	200
8.2.2.1	Radiation Pattern	200
8.2.2.2	Antenna Gain	201
8.2.2.3	Beam width and Effective Area	202
8.2.2.4	Radiation Resistance and Bandwidth	203
8.2.2.5	Types of Antenna	204
8.3	Classification of Microwave Sensors	205
8.3.1	Passive Sensors	206
8.3.2	Active Sensors	209

8.3.2.1	Principle of Pulsed Radar	210
8.3.2.2	CW Radar Sensor	211
8.3.2.3	Altimeter	213
8.3.2.4	Rate-of-Climb Meter	215
8.3.2.5	Synthetic Aperture Radar (SAR) Sensor	216
8.4	Industrial / Commercial Applications	217
8.5	Biomedical Applications	221
8.6	Conclusions	222
8.7	References	223
9.	Silicon Micromachining, Microsensors and MEMS	227-266
	— S. Kal	
	<i>Abstract</i>	227
9.1	Introduction	228
9.2	Evolution of Microsensors and MEMS	230
9.3	Micromachining of Silicon	232
9.3.1	Silicon as a Micromachining Material	233
9.3.2	Bulk and Surface Micromachining	234
9.3.2.1	Bulk Micromachining	234
9.3.2.2	Isotropic and Anisotropic Etching of Silicon	235
9.3.2.3	Etch Chemicals for Micromachining of Silicon	239
9.3.2.4	Etch-Stop Techniques	241
9.3.2.5	Surface Micromachining	243
9.3.2.6	Fabrication of Micro-structures using Bulk Micromachining	246
9.4	Silicon Microsensors	250
9.4.1	Thermal Sensors	252
9.4.1.1	Silicon Microbolometer	252
9.4.1.2	Silicon Thermopile IR Detector/Temperature Sensor	256
9.4.2	Micromachined Silicon Pressure Sensor	258
9.4.3	Micromachined Silicon Accelerometer	259
9.4.4	Micromachined Silicon Flow Sensor	261
9.5	Microsystems Technology and MEMS	263
9.6	Future Trends in MEMS	264
9.7	References	265
10.	Design of MEMS Capacitive Accelerometers	267-282
	— K. Biswas, S. Sen, P. K. Dutta	
	<i>Abstract</i>	267
10.1	Introduction	268
10.2	Design Methodology	269
10.3	MEMS Capacitive Accelerometer	271
10.3.1	Design of a MEMS Capacitive Accelerometer	274
10.3.2	Design Steps	275
10.3.3	Optimization	275
10.4	Conclusion	279
10.5	Reference	280

13.8.2 Friend Biquad	362
13.8.3 Three Amplifier Biquads	362
13.9 Conclusion	363
13.10 References	364

Part – D

Image Based Instrumentation

14. Boundary Extraction and Contour Propagation of Heart Image Sequences	365-408
— A. Mishra, P. K. Dutta	
<i>Abstract</i>	367
14.1 General Introduction	368
14.1.1 Boundary Detection for Echocardiographic Images	369
14.1.1.1 Background and Existing Methods for Echocardiography Images	370
14.1.1.2 Performance Evaluation	371
14.1.1.3 Image Segmentation in the Field of MRI and other Modalities	371
14.1.1.4 Segmentation using Snake	372
14.1.2 Active Contour Model	374
14.1.2.1 Snake: An Overview	374
14.1.2.2 Model Considerations	376
14.1.3 Image Preprocessing	376
14.1.4 The Optimization Problem	378
14.1.4.1 Search Area Estimation	378
14.1.4.2 Discretization	379
14.1.5 Solution Approach	381
14.1.5.1 Encoding	381
14.1.5.2 Objective Function Evaluation	381
14.1.5.3 Algorithm	382
14.1.5.4 Contour Initialization and Propagation Strategy	383
14.1.6 Results and Interpretation	384
14.1.6.1 Contour Extraction on Echocardiographic Images	384
14.1.6.2 Comparison with quasi-Newton's Algorithm	386
14.1.6.3 Performance Evaluation	390
14.1.6.4 Genetic Parameters	394
14.1.7 Boundary Detection on MRI Images	394
14.1.7.1 Description of Cardiac MRI Images	394
14.1.7.2 Sequencing and User Interaction	396
14.1.7.3 Contour Propagation Strategy in a Spatial Sequence	397
14.1.7.4 Contour Extraction in a Temporal Sequence	399
14.1.7.5 Performance Evaluation	403
14.1.8 Conclusion	405
14.2 References	406

15. Remote Sensing— An Overview	409-428
— <i>S. Sengupta</i>	
<i>Abstract</i>	409
15.1 Introduction	410
15.2 Electromagnetic Radiation	412
15.3 Effects of Atmosphere	413
15.3.1 Atmospheric Transmission Windows	413
15.3.2 Effects of Atmospheric Absorption on Remote Sensing Images	414
15.3.3 Effects of Atmospheric Scattering on Remote Sensing Images	414
15.4 Spaceborne Sensors	415
15.4.1 Optical Sensors	415
15.4.2 Microwave Imaging	416
15.5 Satellite Orbits	418
15.5.1 Geostationary Orbits	419
15.5.2 Sun Synchronous Orbits	419
15.5.3 Remote Sensing Satellites	419
15.5.3.1 LANDSAT -4, 5 Orbit Parameters	420
15.5.3.2 SPOT (Satellite Pour l'Observation de la Terre), France	421
15.5.3.3 IRS	422
15.5.3.4 ERS European Remote Sensing Satellite, European Space Agency	423
15.5.3.5 JERS-1	424
15.5.3.6 RADARSAT, Canada	424
15.5.3.7 Meteorological Satellites	425
15.6 Digital Image	426
15.7 Conclusions	427
15.8 References	428

Part – E

Intelligent and Virtual Instrumentation

16. Sensor Fusion & Estimation in Instrumentation	431-454
— <i>S. Bhattacharya, R. Perla, S. Mukhopadhyay</i>	
<i>Abstract</i>	431
16.1 Introduction	432
16.2 Multiple Sensor Fusion using Analytical Redundancy for Sensor Fault Tolerance	433
16.2.1 Case Study: Sensor Validation using Artificial Neural Networks	434
16.2.2 Estimator Performance in FDI	437
16.3 Sensor Data Fusion to Improve Measurement Accuracy in Presence of Noise	440

22. Bioprocess Instrumentation	579-622
— S. Sinha, P. S. Pal	
<i>Abstract</i>	579
22.1 Introduction	580
22.2 Bioprocess Modeling	581
22.2.1 Single and Double Limiting Substrate	582
22.2.2 Mathematical Model	582
22.2.3 Simulation Experiment based on the Mathematical Model	584
22.2.3.1 Batch Process Simulation	584
22.2.3.2 Continuous Mode of Operation without Recycle Flow	586
22.2.3.3 Continuous Mode of Operation with Recycle Flow	586
22.3 See-Saw Bioreactor, Dynamics of Fluid Flow and Oxygen Transfer Characteristics	588
22.3.1 Dynamics of Fluid Flow in See-Saw Bioreactor	588
22.3.1.1 The Transfer Function and its Simulation	590
22.3.2 Oxygen Transfer characteristics in See-Saw Bioreactor	592
22.3.2.1 Modeling of Oxygen Transfer Co-efficient in 'See-Saw' Bioreactor	593
22.3.2.2 Oxygen Transfer through the Falling Film	595
22.3.2.3 Oxygen Transfer through the Flat Top Surface	595
22.3.2.4 Total Oxygen Transfer in the Bioreactor	595
22.3.2.5 Suggested Modification in the Expression for K_L	595
22.4 Dissolved Oxygen (DO) Sensor	598
22.4.1 Review of DO Electrodes	598
22.4.2 Principle of DO Measurement	600
22.4.3 Design of Electrode	602
22.4.4 Designs Fabrication and Testing of the Laboratory DO Electrode and its Associated Instrumentation	603
22.5 A Sliding Mode Observer for Bioprocess Variables	607
22.5.1 Review of Nonlinear Observers	607
22.5.2 Introduction to Variable Structure Control	608
22.5.3 Walcott and Zak SMO	608
22.5.3.1 Basic Theory	609
22.5.3.2 Canonical form Algorithm	610
22.5.3.3 Synthesis of Observer	610
22.5.4 Design of Sliding Mode Observers	612
22.5.4.1 Problem Formulation	612
22.5.4.2 Design Matrices	614
22.5.4.3 Results	615
22.6 Conclusions	619
22.7 Reference	619

23. Measurement of Two Phase Flow Parameters	623-660
(Void Fraction and Flow Rate)	
— <i>P. K. Das</i>	
<i>Abstract</i>	623
23.1 Introduction	624
23.2 Measurement of Void Fraction (α)	626
23.2.1 Definitions of Void Fractions	627
23.2.2 Mechanical Techniques	629
23.2.2.1 Direct Volume Measurement by Quick Closing Valve Technique	629
23.2.2.2 Measurement of Void Fraction by Pressure Drop	630
23.2.3 Radiation Absorption and Scattering Methods	631
23.2.4 Optical Techniques	633
23.2.4.1 Photographic Techniques	633
23.2.4.2 Local Measurements by Intrusive Probes	634
23.2.4.3 Fluorescence Technique	635
23.2.4.4 Scattering Technique	635
23.2.5 Impedance Method	636
23.2.5.1 Separated Flow of Gas and Liquid	637
23.2.6 Other Methods	643
23.2.7 Tomographic Imaging	643
23.3 Flow Rate Measurement	644
23.3.1 Separate Estimation of the Phase Flow Rates	645
23.3.2 Measurement after Flow Stabilization or Homogenization	647
23.3.2.1 Velocity Measurement	647
23.3.2.2 Electromagnetic Method	648
23.3.2.3 Ultrasonic Method	648
23.3.2.4 Laser Method	648
23.3.3 Cross-correlation Technique	649
23.3.3.1 Digital Cross-correlation	650
23.3.3.2 Polarity Cross-correlation	650
23.3.3.3 Henry's Algorithm	651
23.3.3.4 Selection of Cross-correlation Flowmeter Sensors	652
23.3.4 True Mass Flowmeters	655
23.3.4.1 Coriolis Technique	655
23.3.4.2 Gyroscopic Technique	656
23.4 Concluding Remarks	657
23.5 Nomenclature	657
23.6 References	658
<i>Index</i>	661