

Contents

Foreword	v
Acknowledgments	vii
About the Editor	ix
Contributors	xix
List of Acronyms	xxi
1 Introduction	1
<i>Omer Aziz, Benny Lo, Ara Darzi, and Guang-Zhong Yang</i>	
1.1 Wireless Sensor Networks	1
1.2 BSN and Healthcare	4
1.2.1 Monitoring Patients with Chronic Disease	6
1.2.2 Monitoring Hospital Patients	7
1.2.3 Monitoring Elderly Patients	9
1.3 Pervasive Patient Monitoring	10
1.4 Technical Challenges Facing BSN	13
1.4.1 Improved Sensor Design	13
1.4.2 Biocompatibility	14
1.4.3 Energy Supply and Demand	15
1.4.4 System Security and Reliability	16
1.4.5 Context Awareness	18
1.4.6 Integrated Therapeutic Systems	19
1.5 Personalised Healthcare	20
1.6 Finding the Ideal Architecture for BSN	22
1.7 The Future: Going from “Micro” to “Nano”	27
1.8 The Scope of the Book	30
References	34
2 Biosensor Design and Interfacing	41
<i>Bhavik A. Patel, Costas A. Anastassiou, and Danny O’Hare</i>	
2.1 Introduction	41
2.1.1 What Is a Biosensor?	42

2.2	How Do Electrochemical Devices Work?	44
	2.2.1 <i>Potentiometric Devices</i>	45
	2.2.2 <i>Amperometry and Voltammetry</i>	53
2.3	Instrumentation	65
	2.3.1 <i>Potentiometry</i>	65
	2.3.2 <i>Amperometry and Voltammetry</i>	66
	2.3.3 <i>Reference and Counter Electrodes</i>	68
2.4	Photoelectrochemistry and Spectroelectrochemistry	69
2.5	Biocompatibility	71
	2.5.1 <i>Sensor Fouling</i>	71
	2.5.2 <i>Tissue Damage</i>	73
2.6	Novel Approaches to Handling Sensor Data	73
2.7	Conclusions	80
	Acknowledgments	82
	References	82
3	Protein Engineering for Biosensors	89
	<i>Anna Radomska, Suket Singhal, and Tony Cass</i>	
3.1	Introduction	89
	3.1.1 <i>Electrochemical Sensors</i>	90
	3.1.2 <i>Optical Sensors</i>	91
	3.1.3 <i>Gravimetric Sensors</i>	92
	3.1.4 <i>Consuming and Non-Consuming Biosensors</i>	92
3.2	Protein Engineering	93
	3.2.1 <i>The Signal Transduction Module</i>	95
	3.2.2 <i>The Recognition Site Module</i>	97
	3.2.3 <i>Immobilisation Module</i>	100
3.3	Biocompatibility and Implantation	102
3.4	Conclusions	109
	References	109
4	Wireless Communication	117
	<i>Henry Higgins</i>	
4.1	Introduction	117
4.2	Inductive Coupling	118
4.3	RF Communication in Body	119
4.4	Antenna Design	121
4.5	Antenna Testing	125
	4.5.1 <i>Antenna Impedance and Radiation Resistance Measurement</i>	125
	4.5.2 <i>Quarter Wave Line Impedance Measurement</i>	126
4.6	Matching Network	128
	4.6.1 <i>Transmitter Tuning</i>	128

4.6.2	<i>The L Network</i>	130
4.6.3	<i>The π Network</i>	131
4.6.4	<i>The T and π-L Networks</i>	132
4.6.5	<i>Parasitic Effects</i>	133
4.6.6	<i>Network Choice</i>	134
4.6.7	<i>Radio Frequency Losses in Components and Layout Issues</i>	135
4.6.8	<i>Receiver Tuning</i>	135
4.6.9	<i>Base Station Antennas</i>	136
4.7	Propagation	136
4.8	Materials	137
4.9	Environment	138
4.10	External Transceiver (Base Station)	138
4.11	Power Considerations	139
4.11.1	<i>Battery Challenges</i>	140
4.12	Defibrillation Pulse	141
4.13	Link Budget	142
4.14	Conclusions	142
	References	143
5	Network Topologies, Communication Protocols, and Standards	145
	<i>Javier Espina, Thomas Falck, and Oliver Mülhens</i>	
5.1	Network Topologies	145
5.2	Body Sensor Network Application Scenarios	148
5.2.1	<i>Stand-Alone Body Sensor Networks</i>	148
5.2.2	<i>Global Healthcare Connectivity</i>	149
5.2.3	<i>Pervasive Sensor Networks</i>	150
5.3	Wireless Personal Area Network Technologies	152
5.3.1	<i>Overview</i>	152
5.3.2	<i>The Wireless Regulatory Environment</i>	153
5.3.3	<i>Wireless Communication Standards</i>	155
5.3.4	<i>IEEE 802.15.1: Medium-Rate Wireless Personal Area Networks</i>	155
5.3.5	<i>IEEE P802.15.3: High-Rate Wireless Personal Area Networks</i>	158
5.3.6	<i>IEEE 802.15.4: Low-Rate Wireless Personal Area Networks</i>	160
5.3.7	<i>ZigBee</i>	164
5.3.8	<i>Comparison of Technologies</i>	168
5.4	Practical Experiences with IEEE 802.15.4	169
5.5	Healthcare System Integration	174
5.5.1	<i>Existing Interoperability Standards</i>	174
5.5.2	<i>Wireless Interoperability Standards Under Development</i>	176
5.6	Conclusions	177
	References	180

6	Energy Scavenging	183
	<i>Eric Yeatman and Paul Mitcheson</i>	
6.1	Introduction	183
	6.1.1 <i>Sensor Node Power Requirements</i>	184
	6.1.2 <i>Batteries and Fuel Cells for Sensor Nodes</i>	185
	6.1.3 <i>Ambient Energy Sources</i>	186
6.2	Architectures for Inertial Energy Scavenging	187
	6.2.1 <i>Energy Extraction Mechanisms for Inertial Generators</i>	187
	6.2.2 <i>Performance Limits</i>	191
6.3	Fabrication and Testing	195
	6.3.1 <i>Device Fabrication and Structure</i>	195
	6.3.2 <i>Device Testing</i>	197
6.4	Module Design and Simulation	200
	6.4.1 <i>System Modelling</i>	200
	6.4.2 <i>Integrated Simulation</i>	204
6.5	Power Electronics and System Effectiveness	205
	6.5.1 <i>Power Electronics Requirements and Trade-Offs</i>	205
	6.5.2 <i>Semiconductor Device Design</i>	209
	6.5.3 <i>Coherent Simulation</i>	211
6.6	Discussion and Conclusions	213
	6.6.1 <i>What Is Achievable in Body-Sensor Energy Scavenging?</i>	213
	6.6.2 <i>Future Prospects and Trends</i>	215
	References	216
7	Towards Ultra-Low Power Bio-Inspired Processing	219
	<i>Leila Shepherd, Timothy G. Constandinou, and Chris Toumazou</i>	
7.1	Introduction	219
7.2	Bio-Inspired Signal Processing	220
7.3	Analogue vs Digital Signal Processing	221
	7.3.1 <i>Quantised Data/Time vs Continuous Data/Time</i>	221
	7.3.2 <i>Analogue/Digital Data Representation</i>	222
	7.3.3 <i>Linear Operations</i>	223
	7.3.4 <i>Non-Linear Operations</i>	224
	7.3.5 <i>Hybrid System Organisation</i>	224
7.4	CMOS-Based Biosensors	225
	7.4.1 <i>Ion-Sensitive Field-Effect Transistor (ISFET)</i>	227
	7.4.2 <i>ISFET-Based Biosensors</i>	229
	7.4.3 <i>Towards Biochemically Inspired Processing with ISFETs</i>	230
7.5	Applications of Ultra-Low Power Signal Processing for BSN	234
	References	236

8	Multi-Sensor Fusion	239
	<i>Guang-Zhong Yang and Xiaopeng Hu</i>	
8.1	Introduction	239
	8.1.1 <i>Information Interaction</i>	240
	8.1.2 <i>Levels of Processing</i>	242
8.2	Direct Data Fusion	242
	8.2.1 <i>Optimal Averaging for Sensor Arrays</i>	243
	8.2.2 <i>Source Recovery</i>	246
8.3	Feature-Level Fusion	252
	8.3.1 <i>Feature Detection</i>	252
	8.3.2 <i>Distance Metrics</i>	253
	8.3.3 <i>Instance-Based Learning</i>	254
	8.3.4 <i>Distance-Based Clustering</i>	255
8.4	Dimensionality Reduction	258
	8.4.1 <i>Multidimensional Scaling (MDS)</i>	259
	8.4.2 <i>Locally Linear Embedding (LLE)</i>	260
	8.4.3 <i>Isometric Mapping (Isomap)</i>	261
8.5	Feature Selection	262
	8.5.1 <i>Feature Relevance</i>	264
	8.5.2 <i>Feature Relevance Based on ROC Analysis</i>	266
	8.5.3 <i>Feature Selection Based on ROC Analysis</i>	271
8.6	Decision-Level Fusion	274
8.7	Conclusions	278
	References	281
9	Context-Aware Sensing	287
	<i>Surapa Thiemjarus and Guang-Zhong Yang</i>	
9.1	Introduction	287
9.2	Application Scenarios	289
9.3	Preprocessing for Context Sensing	291
	9.3.1 <i>Information Granularity</i>	291
	9.3.2 <i>Sources of Signal Variations</i>	292
	9.3.3 <i>Data Normalisation</i>	293
9.4	Context Recognition Techniques	294
	9.4.1 <i>Hidden Markov Models (HMMs)</i>	294
	9.4.2 <i>Artificial Neural Networks (ANNs)</i>	302
9.5	Spatio-Temporal Self-Organising Maps (STSOMs)	306
	9.5.1 <i>The Basic Structure of the STSOM</i>	307
	9.5.2 <i>The Use of Multi-Resolution for Improved Class Separation</i>	312
	9.5.3 <i>STSOM Algorithm Design</i>	315
	9.5.4 <i>STSOM for Context-Aware Sensing</i>	320
9.6	Conclusions	323
	References	326

10	Autonomic Sensing	333
	<i>Guang-Zhong Yang, Benny Lo, and Surapa Thiemjarus</i>	
10.1	Introduction	333
10.2	Autonomic Sensing	334
10.3	Fault Detection and Self-Healing	336
	<i>10.3.1 Belief Networks</i>	337
	<i>10.3.2 Belief Propagation Through Message Passing</i>	339
10.4	Routing and Self-Organisation	344
10.5	Security and Self-Protection	348
	<i>10.5.1 Bacterial Attacks</i>	350
	<i>10.5.2 Virus Infection</i>	356
	<i>10.5.3 Secured Protocols</i>	358
	<i>10.5.4 Self-Protection</i>	362
10.6	Conclusions	365
	References	366
11	Wireless Sensor Microsystem Design: A Practical Perspective	373
	<i>David R. S. Cumming, Paul A. Hammond, Lei Wang, Jonathan M. Cooper, and Erik A. Johannessen</i>	
11.1	Introduction	373
11.2	The Diagnostic Capsule	375
11.3	Applications for Wireless Capsule Devices	376
	<i>11.3.1 Human Medicine</i>	376
	<i>11.3.2 Animal Applications</i>	378
11.4	Technology	379
	<i>11.4.1 Design Constraints</i>	379
	<i>11.4.2 Microsystem Design</i>	379
	<i>11.4.3 Integrated Sensors</i>	381
11.5	Electronics System Design	385
	<i>11.5.1 Analogue Electronic Front-End Acquisition Design</i>	386
	<i>11.5.2 Digital System Design</i>	386
11.6	The Wireless Environment	388
11.7	Power Sources	390
11.8	Packaging	391
11.9	Conclusions	392
	References	393
12	Conclusions and Future Outlook	399
	<i>Guang-Zhong Yang</i>	

Appendix A	Wireless Sensor Development Platforms	403
	<i>Benny Lo and Guang-Zhong Yang</i>	
A.1	Introduction	403
A.2	System Architecture	403
	<i>A.2.1 Processor</i>	404
	<i>A.2.2 Wireless Communication</i>	407
	<i>A.2.3 Memory</i>	410
	<i>A.2.4 Sensor Interface</i>	411
	<i>A.2.5 Power Supply</i>	414
	<i>A.2.6 Operating System</i>	415
A.3	Conclusions	418
	References	418
Appendix B	BSN Development Kit and Programming Guide	423
	<i>Benny Lo and Guang-Zhong Yang</i>	
B.1	Introduction	423
B.2	BSN Architectural Design	423
	<i>B.2.1 Microcontroller</i>	425
	<i>B.2.2 Radio Transceiver</i>	428
	<i>B.2.3 Flash Memory</i>	437
	<i>B.2.4 Board Connector</i>	438
	<i>B.2.5 Antenna</i>	440
B.3	BSN Development Kit	441
	<i>B.3.1 BSN Nodes</i>	442
	<i>B.3.2 USB Programmer</i>	442
	<i>B.3.3 Sensor Board</i>	443
	<i>B.3.4 Battery Board</i>	447
	<i>B.3.5 Prototype Board</i>	449
B.4	TinyOS	451
	<i>B.4.1 nesC</i>	452
	<i>B.4.2 Execution Model</i>	458
	<i>B.4.3 Hardware Abstraction</i>	460
	<i>B.4.4 TOSSIM</i>	461
	<i>B.4.5 Deluge – TinyOS Network Programming</i>	466
B.5	BSN Programming Guide	468
	<i>B.5.1 Programming Environment</i>	468
	<i>B.5.2 Installation Instructions</i>	469
	<i>B.5.3 BSN Node Programming</i>	469
B.6	Conclusions	478
	References	478
Index		481