

Contents

List of Figures	xiii
List of Tables	xxv
Preface.....	xxvii
Acknowledgments	xxix
Author.....	xxxii

1. Introduction	1
1.1 Why Is Environmental Monitoring?	1
1.2 Environmental Systems, Ecosystems, and Planet Earth	2
1.3 Example	3
1.4 Interactions in the Natural Environment	5
1.5 Human Interactions with the Environment.....	5
1.6 From Measuring to Knowing: Analysis and Modeling	6
1.7 Continuous Real-Time Monitoring.....	7
1.8 Data Management and the World Wide Web	7
1.9 Interdisciplinary.....	8
1.10 Scales.....	8
1.11 Sampling.....	9
1.11.1 Detection Limits.....	9
1.11.2 Rounding Numbers.....	9
1.11.3 Precision and Accuracy.....	9
1.12 Ground-Based, Airborne, and Spaceborne Platforms	11
1.13 More on Applications	11
1.13.1 Examples of Programs and Agencies	12
Supplementary Reading	13
Exercises	13

Section I From Sensors to Systems

2. Sensors and Transducers: Basic Circuits	17
2.1 Principles of Electrical Quantities	17
2.2 Circuits: Nodes and Loops	21
2.3 Measuring Voltages, Currents, and Resistances.....	25
2.4 Sensors.....	28
2.5 From Sensors to Transducers	29
2.6 Sensor Specifications: Static.....	29
2.7 Resistive Sensors	30
2.8 Example: From a Light Sensor to a Light Transducer.....	30
2.9 Example: From Thermistor to Temperature Transducer.....	39

2.10	Example: Temperature Transducer for Air, Soil, and Water	46
2.11	Example: Thermocouples.....	49
2.12	Examples: Using Thermocouples.....	54
	Supplementary Reading	54
	Exercises	55
3.	Sensors and Transducers: Bridge Circuits.....	57
3.1	Introduction	57
3.2	Balanced Source Voltage Divider.....	57
3.3	One-Sensor Circuit: Quarter-Bridge	63
3.4	Two-Sensor Circuit: Half-Bridge.....	64
3.5	Two-Sensor Having Opposite Effect: Half-Bridge	65
3.6	Four Sensor Circuit: Full Bridge	66
3.7	Zero Adjust and Range Adjust.....	69
3.8	Sensor Specifications	69
3.9	Electrochemical Sensors	71
3.10	Example: Dynamic Specifications and a Potentiometer-Based Wind Direction.....	74
3.11	Dielectric Properties	74
3.12	Example: Piezoelectric Sensors	76
3.13	Example: Soil Tensiometer	76
	Exercises	77
4.	Signal Conditioning and Analog-to-Digital Converters	79
4.1	Introduction	79
4.2	Operational Amplifiers	79
4.3	Linearization of the Bridge Circuit Output.....	82
4.4	Common-Mode Rejection	83
4.5	Instrumentation Amplifier	84
4.6	Spectrum	85
4.7	Noise	86
4.8	Electric Field and Electrostatic Shielding	87
4.9	Isolation	89
4.10	Cold-Junction Compensation	89
4.11	Analog-to-Digital Converter.....	90
4.12	Current Loop: 4–20 mA.....	92
4.13	Pulse Sensors	94
	Exercises	95
5.	Data Acquisition Systems	97
5.1	Introduction	97
5.2	Dataloggers	97
5.3	Applications in Environmental Monitoring	99
5.4	Analog Channels.....	99
5.5	Real-Time Clock.....	100

5.6	Communications with a Datalogger	102
5.6.1	Baud Rate and Serial Communication	102
5.6.2	Data, Parity, and Stop (D/P/S) Bits.....	102
5.7	RS-232 Standard	103
5.8	SDI-12	106
5.9	Conditions and Enclosures.....	106
5.10	Datalogger Example: CR1000	108
5.11	VoltSE.....	113
5.12	VoltDiff	113
5.13	BrHalf.....	113
5.14	BrFull.....	114
5.15	PulseCount.....	114
5.16	Supervisory Control and Data Acquisition.....	117
	Exercises	117
6.	Single-Board Computers and Microcontrollers	119
6.1	Introduction	119
6.2	Computer Organization and Architecture.....	119
6.3	Single-Board Computers.....	120
6.4	ARM Architectures.....	121
6.5	SBC Based on ARM Processor: Example.....	121
6.6	System on a Chip.....	121
6.7	SBC Example: Raspberry Pi.....	122
6.8	Microcontrollers	123
6.9	MCU Example	125
6.10	In-Circuit Serial Programming.....	125
6.11	MCU-Based SBC Example: Arduino	126
6.12	Comparing SBCs: TS-7400, Raspberry Pi, Arduino Uno	127
6.13	MCUs as DAS.....	128
6.14	Example: Arduino Programming.....	129
6.15	Example: Using Flash Memory for Datalogging with Arduino	133
6.16	Example: Using a Datalogger Shield for Arduino.....	136
6.17	Example MCU-Based SBC	137
	Exercises	138
7.	Wireless Technologies and Telemetry.....	139
7.1	Introduction	139
7.2	Wave Concepts	139
7.3	Radio Wave Spectrum	140
7.4	Radio Wave Propagation.....	141
7.5	Propagation Models.....	143
7.5.1	Free-Space Propagation Model.....	143
7.5.2	Two-Ray Propagation Model	145
7.6	Phase Shift.....	146

7.7	Fresnel Zones.....	147
7.8	Absorption.....	148
7.9	Radio Frequency Cables.....	148
7.10	Power in dBm.....	149
7.11	Antennas.....	149
7.12	Fade Margin.....	150
7.13	Polarization.....	151
7.14	Modulation: Digital Signals.....	151
7.15	Multiplexing.....	152
7.16	Spread Spectrum.....	153
7.17	Wi-Fi.....	153
7.18	Example: Low-Cost Wi-Fi Radio.....	154
7.19	Example: Establishing a Wi-Fi Link to Connect a Weather Station to the Internet.....	155
7.20	Cellular Phone Network.....	157
7.21	Argos.....	158
	Exercises.....	158
8.	Wireless Sensor Networks.....	159
8.1	Introduction.....	159
8.2	WSN Nodes.....	159
8.2.1	Example of a Two-Module Sensor Node: Crossbow IRIS and MDA.....	162
8.2.2	Example of an Integrated Sensor Node: Moteinos.....	163
8.3	Networks: OSI Model.....	163
8.4	Media Access Control.....	164
8.5	Multihop Wireless Communication.....	164
8.6	Network Protocol for Environmental Monitoring.....	165
8.7	Radio Propagation and WSN.....	166
8.8	Example of Radio Propagation Experiments.....	167
8.9	Example: WSN for Soil Moisture in a Hardwood Bottomland Forest.....	168
8.10	WSN: Energy Scavenging.....	172
	Exercises.....	173
9.	Power.....	175
9.1	Introduction.....	175
9.2	Photovoltaic.....	175
9.3	Solar Radiation and Efficiency.....	177
9.4	Solar Cell Model.....	179
9.5	From Cell to Module.....	186
9.6	Shading and Bypass Diode.....	187
9.7	Load and Power.....	188