Practical Interfacing in the Laboratory

Using a PC for instrumentation, data analysis, and control

Stephen E. Derenzo

CAMBRIDGE

Contents

Preface xiii
Acknowledgments xvii

1 Digital tools 1

1.1 Introduction 1
1.2 The microcomputer 2
1.3 Number systems 5
1.4 Digital building blocks 8
1.5 Digital counters/timers 13
1.6 Parallel and serial input/output ports 18
1.7 Digital data-acquisition procedures 29
1.8 Switch debouncing 33
1.9 Digital interfacing standards 35
1.10 Problems 44
1.11 Additional reading 51

Laboratory exercises

1. Introduction to C programming 53
2. Measuring event times 58
3. Digital interfacing: switches and lights 66

2 Analog tools 75

2.1 Introduction 75
2.2 Operational-amplifier circuits 76
2.3 Op-amp characteristics 85
2.4 Instrumentation and isolation amplifiers 89

2.5 Noise sources 94
2.6 Analog filtering 98
2.7 The power amplifier 117
2.8 Problems 118
2.9 Additional reading 127

Laboratory exercises

4. Operational-amplifier circuits 128
5. Instrumentation amplifiers 136
6. Analog filtering 145

3 Analog ↔ digital conversion and sampling 153

3.1 Introduction 153
3.2 Digital-to-analog converter circuits 153
3.3 Analog-to-digital converter circuits 161
3.4 The sample-and-hold amplifier 173
3.5 Sampling analog waveforms 180
3.6 Frequency aliasing 183
3.7 Available data-acquisition systems 186
3.8 Problems 187
3.9 Additional reading 200

Laboratory exercises

7. Introduction to A/D and D/A conversion 201
8. D/A conversion and waveform generation 206
9. A/D conversion and periodic sampling 213
10. Frequency aliasing 221

4 Sensors and actuators 226

4.1 Introduction 226
4.2 Position and angle sensors 228
4.3 Temperature transducers 234
4.4 Strain-sensing elements 253
4.5 Force and pressure transducers 255
4.6 Measuring light 261
4.7 Producing visible light 268

4.8 Ionic potentials 271
4.9 The detection and measurement of ionizing radiation 274
4.10 Measuring time 277
4.11 Problems 278
4.12 Additional reading 298

Laboratory exercises

11. Measuring angular position 300
12. Measuring temperature 305
13. Measuring strain and force 311
14. Measuring light with a photodiode 316
15. The thermoelectric heat pump 322
16. Electrodes and ionic media 329
17. The human heart 334
18. The electromyogram (EMG) 343
19. The electrooculogram (EOG) 352

5 Data analysis and control 360

5.1 Introduction 360
5.2 The Gaussian-error distribution 360
5.3 Student's t test 366
5.4 Least-squares fitting 372
5.5 The chi-squared statistic 375
5.6 Solving nonlinear equations 379
5.7 Monte Carlo simulation 383
5.8 Fourier transforms 385
5.9 Digital filters 415
5.10 Control techniques 419
5.11 Problems 427
5.12 Additional reading 448

Laboratory exercises

20. Analog ↔ digital conversion and least-squares fitting 449
21. Fast Fourier transforms of sampled data 454
22. Fast Fourier transforms of the human voice 461
23. Digital filtering 471
24. Process compensation using Fourier deconvolution and digital filtering 477
25. Analog temperature control using a resistive heater 485

26. Temperature control using the computer and a resistive heater 490
27. Temperature control using the computer and a thermoelectric heat pump 497

Appendix A Grounding and shielding 504
A.1 Introduction 504
A.2 Interference noise due to common impedance 504
A.3 Interference noise due to capacitive coupling 505
A.4 General rules to follow 506

Appendix B Experimental uncertainties 508
B.1 Multimeter accuracy 508
B.2 Propagation of random error 508

Appendix C C programming tips 510
C.1 Declare all variables 510
C.2 Arithmetic statements 510
C.3 Conditional tests 511
C.4 Conditional operators 511
C.5 Indexed looping 511
C.6 Bitwise logical operators 512
C.7 Increment and decrement operators 512
C.8 The printf statement 513
C.9 Defining your own functions 513
C.10 "Including" your own functions 514
C.11 Opening and writing to files of arbitrary name 515
C.12 Using library functions 515
C.13 Allocating large storage arrays 516
C.14 General format rules for C programs 516

Appendix D Numerical methods and C functions 517
D.1 Introduction 517
D.2 Fast Fourier transform 517
D.3 Minimization function PARFIT 520
D.4 The uncertainty estimation function VARFIT 529
D.5 Numerical evaluation of functions defined by integrals 542
D.6 Function inversion using Newton's method 549
D.7 Function inversion using quadratic approximation 549
D.8 Random number generator 550

Appendix E Summary of Data Translation DT3010 PCI plug-in card 553
E.1 Introduction 553
E.2 Parallel output 553
E.3 Parallel input 556

E.4 Analog output 556
E.5 Analog input 557
E.6 Using the DT3010 board with the Microsoft visual C++ compiler 557

Appendix F Using the digital oscilloscope to record waveforms 558
F.1 Introduction 558
F.2 Capturing the waveform 558
F.3 Printing the waveform 558

Appendix G Electrical hazards and safety 560
G.1 Introduction 560
G.2 Electrical power 561
G.3 The ground fault interrupter circuit 563
G.4 The isolation transformer 564
G.5 Typical accident scenarios 564
G.6 Methods of accident prevention 564

Appendix H Standard resistor and capacitor values 566
H.1 Standard resistor values and color codes 566
H.2 Standard capacitor values and codes 566

Appendix I ASCII character codes 569
I.1 ASCII character set codes 569

Glossary 572
Index 602