

Contents

Preface

xi

I. Introduction

1

1. Introducing mechatronics

3

Chapter objectives

3

1.1 What is mechatronics?

3

1.2 The design process

5

1.3 Systems

6

1.4 Measurement systems

8

1.5 Control systems

9

1.6 Programmable logic controller

21

1.7 Examples of mechatronic systems

22

Summary

26

Problems

27

II. Sensors and signal conditioning

29

2. Sensors and transducers

31

Chapter objectives

31

2.1 Sensors and transducers

31

2.2 Performance terminology

32

2.3 Displacement, position and proximity

37

2.4 Velocity and motion

54

2.5 Force

57

2.6 Fluid pressure

57

2.7 Liquid flow

61

2.8 Liquid level

62

2.9 Temperature

63

2.10 Light sensors

69

2.11 Selection of sensors

70

2.12 Inputting data by switches

71

Summary

74

Problems

75

3. Signal conditioning

78

Chapter objectives

78

3.1 Signal conditioning

78

3.2 The operational amplifier

79

3.3 Protection

90

3.4 Filtering

91

3.5 Wheatstone bridge

92

3.6 Pulse modulation

97

3.7 Problems with signals

98

3.8 Power transfer

100

Summary

101

Problems

101

4. Digital signals

103

Chapter objectives

103

4.1 Digital signals

103

4.2 Analogue and digital signals

103

4.3 Digital-to-analogue and analogue-to-digital converters

107

4.4 Multiplexers

113

4.5 Data acquisition

114

4.6 Digital signal processing

116

4.7 Digital signal communications

118

Summary

119

Problems

120

5. Digital logic

121

Chapter objectives

121

5.1 Digital logic

121

5.2 Logic gates

122

5.3 Applications of logic gates

130

5.4 Sequential logic

135

Summary

143

Problems

143

6. Data presentation systems	146	9. Electrical actuation systems	222
Chapter objectives	146	Chapter objectives	222
6.1 Displays	146	9.1 Electrical systems	222
6.2 Data presentation elements	147	9.2 Mechanical switches	222
6.3 Magnetic recording	152	9.3 Solid-state switches	224
6.4 Optical recording	157	9.4 Solenoids	231
6.5 Displays	157	9.5 Direct current motors	232
6.6 Data acquisition systems	162	9.6 Alternating current motors	241
6.7 Measurement systems	166	9.7 Stepper motors	243
6.8 Testing and calibration	169	9.8 Direct current servomotors	250
Summary	171	9.9 Motor selection	251
Problems	172	Summary	255
		Problems	255
III. Actuation	175	IV. Microprocessor systems	257
7. Pneumatic and hydraulic actuation systems	177	10. Microprocessors and microcontrollers	259
Chapter objectives	177	Chapter objectives	259
7.1 Actuation systems	177	10.1 Control	259
7.2 Pneumatic and hydraulic systems	177	10.2 Microprocessor systems	259
7.3 Directional control valves	181	10.3 Microcontrollers	270
7.4 Pressure control valves	186	10.4 Applications	296
7.5 Cylinders	188	10.5 Programming	297
7.6 Servo and proportional control valves	192	Summary	300
7.7 Process control valves	193	Problems	300
Summary	198		
Problems	198	11. Assembly language	301
		Chapter objectives	301
8. Mechanical actuation systems	201	11.1 Languages	301
Chapter objectives	201	11.2 Assembly language programs	302
8.1 Mechanical systems	201	11.3 Instruction sets	304
8.2 Types of motion	202	11.4 Subroutines	317
8.3 Kinematic chains	204	11.5 Look-up tables	321
8.4 Cams	208	11.6 Embedded systems	324
8.5 Gears	210	Summary	327
8.6 Ratchet and pawl	214	Problems	328
8.7 Belt and chain drives	214		
8.8 Bearings	216	12. C language	329
8.9 Electromechanical linear actuators	218	Chapter objectives	329
Summary	219	12.1 Why C?	329
Problems	220	12.2 Program structure	329

12.3	Branches and loops	336
12.4	Arrays	340
12.5	Pointers	342
12.6	Program development	343
12.7	Examples of programs	345
12.8	Arduino programs	348
	Summary	352
	Problems	352

13. Input/output systems 354

	Chapter objectives	354
13.1	Interfacing	354
13.2	Input/output addressing	355
13.3	Interface requirements	357
13.4	Peripheral interface adapters	364
13.5	Serial communications interface	369
13.6	Examples of interfacing	372
	Summary	380
	Problems	380

14. Programmable logic controllers 382

	Chapter objectives	382
14.1	Programmable logic controller	382
14.2	Basic PLC structure	382
14.3	Input/output processing	386
14.4	Ladder programming	387
14.5	Instruction lists	391
14.6	Latching and internal relays	394
14.7	Sequencing	396
14.8	Timers and counters	397
14.9	Shift registers	400
14.10	Master and jump controls	401
14.11	Data handling	402
14.12	Analogue input/output	404
	Summary	406
	Problems	407

15. Communication systems 409

	Chapter objectives	409
15.1	Digital communications	409
15.2	Centralised, hierarchical and distributed control	409
15.3	Networks	412
15.4	Protocols	414

15.5	Open Systems Interconnection communication model	415
15.6	Serial communication interfaces	418
15.7	Parallel communication interfaces	427
15.8	Wireless communications	430
	Summary	431
	Problems	432

16. Fault finding 433

	Chapter objectives	433
16.1	Fault-detection techniques	433
16.2	Watchdog timer	434
16.3	Parity and error coding checks	435
16.4	Common hardware faults	437
16.5	Microprocessor systems	438
16.6	Evaluation and simulation	441
16.7	PLC systems	442
	Summary	445
	Problems	445

V. System models 447

17. Basic system models 449

	Chapter objectives	449
17.1	Mathematical models	449
17.2	Mechanical system building blocks	450
17.3	Electrical system building blocks	458
17.4	Fluid system building blocks	462
17.5	Thermal system building blocks	469
	Summary	472
	Problems	473

18. System models 475

	Chapter objectives	475
18.1	Engineering systems	475
18.2	Rotational-translational systems	475
18.3	Electromechanical systems	476
18.4	Linearity	479
18.5	Hydraulic-mechanical systems	481
	Summary	484
	Problems	484

19. Dynamic responses of systems	485	22.8 Controller tuning	564
Chapter objectives	485	22.9 Velocity control	566
19.1 Modelling dynamic systems	485	22.10 Adaptive control	567
19.2 Terminology	486	Summary	569
19.3 First-order systems	488	Problems	569
19.4 Second-order systems	494		
19.5 Performance measures for second-order systems	501	23. Artificial Intelligence	571
19.6 System identification	504	Chapter objectives	571
Summary	505	23.1 What is meant by artificial intelligence?	571
Problems	506	23.2 Perception and cognition	572
		23.3 Fuzzy logic	575
		Summary	585
		Problems	586
20. System transfer functions	509	VI. Conclusion	587
Chapter objectives	509	24. Mechatronic systems	589
20.1 The transfer function	509	Chapter objectives	589
20.2 First-order systems	512	24.1 Mechatronic designs	589
20.3 Second-order systems	514	24.2 Robotics	600
20.4 Systems in series	516	24.3 Case studies	606
20.5 Systems with feedback loops	517	Summary	625
20.6 Effect of pole location on transient response	519	Problems	625
Summary	522	Research assignments	625
Problems	522	Design assignments	625
		Appendices	627
21. Frequency response	524	A The Laplace transform	629
Chapter objectives	524	A.1 The Laplace transform	629
21.1 Sinusoidal input	524	A.2 Unit steps and impulses	630
21.2 Phasors	525	A.3 Standard Laplace transforms	632
21.3 Frequency response	527	A.4 The inverse transform	636
21.4 Bode plots	530	Problems	638
21.5 Performance specifications	539		
21.6 Stability	541	B Number systems	639
Summary	543	B.1 Number systems	639
Problems	544	B.2 Binary mathematics	640
		B.3 Floating numbers	643
22. Closed-loop controllers	546	B.4 Gray code	643
Chapter objectives	546	Problems	644
22.1 Control processes	546		
22.2 Two-step or on/off mode	548		
22.3 Proportional mode of control	550		
22.4 Integral mode of control	552		
22.5 Derivative mode of control	555		
22.6 PID controller	557		
22.7 Digital control systems	559		

C Boolean algebra	645	C.4 Karnaugh maps Problems	649
C.1 Laws of Boolean algebra	645	Answers	654
C.2 De Morgan's laws	646	Index	669
C.3 Boolean function generation from truth tables	647		

The term *mechatronics* was 'invented' by a Japanese engineer in 1969, as a combination of 'mecha' from mechanisms and 'tronics' from electronics. The word now has a wider meaning, being used to describe a philosophy in engineering technology in which there is a co-ordinated, and concurrently developed, integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes. As a result, many products which used to have mechanical functions have had many replaced with ones involving microprocessors. This has resulted in much greater flexibility, easier redesign and reprogramming, and the ability to carry out automated data collection and reporting.

A consequence of this approach is the need for engineers and technicians to adopt an interdisciplinary and integrated approach to engineering. Thus engineers and technicians need skills and knowledge that are not confined to a single subject area. They need to be capable of operating and communicating across a range of engineering disciplines and linking with those having more specialised skills. This book is an attempt to provide a basic background to mechatronics and provide links through to more specialised skills.

The first edition was designed to cover the Business and Technology Education Council (BTEC) Mechatronics units for Higher National Certificate/Diploma courses for technicians and designed to fit alongside more specialist units such as those for design, manufacture and maintenance determined by the application area of the course. The book was widely used for such courses and has also found use in undergraduate courses in both Britain and the United States. Following feedback from lecturers in both Britain and the United States, the second edition was considerably expanded and with its extra depth it was not only still relevant for its original readership, but also suitable for undergraduate courses. The third edition involved refinements of some explanations, more discussion of microcontrollers and programming, increased use of models for mechatronic systems, and the grouping together of key facts in the Appendices. The fourth edition was a complete reconsideration of all aspects of the text, both layout and content, with some regrouping of topics, movement of more material into Appendices to avoid disrupting the flow of the text, new material – in particular an introduction to artificial intelligence – more case studies and a refinement of some topics to improve clarity. Also, objectives and key point summaries were included with each chapter. The fifth edition kept the same structure but, after consultation with many users of the book, many aspects had extra detail and refinement added.

The sixth edition involved a restructuring of the descriptive parts of the book so that users felt that the chapter sequencing did not match the general teaching sequence. Other changes included the inclusion of material on