
Contents

| | |
|--|----|
| Preface | ix |
| Chapter 1. Control, Servo-mechanisms and System Regulation | 1 |
| 1.1. Introduction | 1 |
| 1.1.1. Generalities and definitions | 1 |
| 1.1.2. Control law synthesis | 5 |
| 1.1.3. Comprehension and application exercises | 7 |
| 1.2. Process control | 11 |
| 1.2.1. Correction in the frequency domain | 11 |
| 1.2.2. Phase advance controller and PD controller | 12 |
| 1.2.3. Phase delay controller and integrator compensator | 14 |
| 1.2.4. Proportional, integral and derivative (PID) control | 17 |
| 1.3. Some application exercises | 23 |
| 1.3.1. Identification of the transfer function and control | 23 |
| 1.3.2. PI control | 30 |
| 1.3.3. Phase advance control | 33 |
| 1.4. Some application exercises | 36 |
| 1.5. Application 1: stabilization of a rigid robot with pneumatic actuator | 39 |
| 1.5.1. Conventional approach | 41 |
| 1.6. Application 2: temperature control of an oven | 51 |
| 1.6.1. Modeling and identification study | 51 |
| Chapter 2. System Process Control | 55 |
| 2.1. Introduction | 55 |
| 2.2. Modeling | 55 |
| 2.2.1. Introduction | 55 |

| | |
|--|----|
| 2.3. Governability, controllability and observability | 56 |
| 2.3.1. Characteristic polynomial, minimal polynomial and Cayley–Hamilton theorem | 56 |
| 2.3.2. Governability or controllability | 56 |
| 2.3.3. Observability | 63 |
| 2.3.4. Observer | 68 |
| 2.3.5. Observer for state reconstruction | 69 |
| 2.3.6. Minimal state–space representation | 76 |
| 2.4. State feedback, control by poles placement and stability | 79 |
| 2.4.1. State feedback control | 79 |
| 2.4.2. Poles placement and stabilizability | 80 |
| 2.4.3. Finite-time response for a discrete system, deadbeat response | 83 |
| 2.4.4. Use of observers in control: separation principle | 85 |
| 2.5. Linear quadratic (LQ) control | 86 |
| 2.5.1. Linear quadratic regulator | 89 |
| 2.6. Optimal control (LQ) | 90 |
| 2.7. Comprehension and application exercises | 94 |

Chapter 3. Actuators: Modeling and Analysis 117

| | |
|--|-----|
| 3.1. Introduction: electric, hydraulic and pneumatic actuators | 117 |
| 3.1.1. Representation methods for physical systems | 118 |
| 3.1.2. Modeling of a few constituents of physical systems | 120 |
| 3.2. Transmission chains, actuators and sensors | 126 |
| 3.2.1. Electric actuators in robotics | 126 |
| 3.2.2. Motor speed torque characteristic | 131 |
| 3.2.3. Dynamic behavior or transient behavior | 131 |
| 3.2.4. Electric systems motor load | 134 |
| 3.3. Pneumatic actuators | 137 |
| 3.3.1. Pneumatic system modeling | 137 |
| 3.3.2. Frictions model | 145 |
| 3.4. Hydraulic actuators | 149 |
| 3.4.1. System description | 149 |
| 3.4.2. Mechanical model | 151 |
| 3.4.3. Hydraulic actuator model | 152 |
| 3.5. Application exercises | 155 |

| | |
|--|-----|
| Chapter 4. Digital Control and Polynomial Approach | 161 |
| 4.1. Introduction to digital control | 161 |
| 4.1.1. Digital controller synthesis by transposition | 162 |
| 4.1.2. Euler's transposition | 164 |
| 4.1.3. Choice of the sampling period (Shannon's theorem) | 170 |
| 4.2. PID controller synthesis and its equivalent digital RST | 171 |
| 4.2.1. Standard controllers | 171 |
| 4.2.2. Study of digital PIDs | 172 |
| 4.2.3. Digital RST controller synthesis | 178 |
| 4.2.4. Choice of poles and zeros to compensate | 179 |
| 4.2.5. Computation of polynomials R , S and T | 180 |
| 4.2.6. Additional objectives for synthesis | 181 |
| 4.3. Digital control by poles placement | 182 |
| 4.3.1. Choice of the sampling period | 183 |
| 4.4. Diophantine, Bézout, greatest common divisor, least common multiple and division | 183 |
| 4.4.1. Polynomial arithmetic | 183 |
| 4.4.2. Diophantine equation $ax + by = c$ and Bachet–Bézout theorem | 184 |
| 4.4.3. Bézout's identity | 185 |
| 4.4.4. Greatest common divisor | 185 |
| 4.4.5. Least common multiple | 185 |
| 4.5. A few comprehension and application exercises | 186 |
| | |
| Chapter 5. NAO Robot | 193 |
| 5.1. Introduction | 193 |
| 5.2. Home care project | 194 |
| 5.2.1. Choregraphe software | 194 |
| 5.2.2. Nao Matlab SDK research | 199 |
| 5.2.3. Nao and home care | 206 |
| 5.2.4. The actions to be made | 207 |
| 5.3. Details of the various programs | 208 |
| 5.3.1. Ask for news | 208 |
| 5.3.2. CallFirefighters box | 212 |
| 5.3.3. CallNeighbor box | 213 |
| 5.3.4. CallFamily box | 215 |
| 5.3.5. Collision detection | 215 |
| 5.3.6. Special actions: waking-up | 216 |
| 5.3.7. Morning hygiene | 220 |
| 5.3.8. Gymnastics | 221 |
| 5.3.9. Nurse call | 225 |
| 5.3.10. Memory game | 227 |
| 5.3.11. Drugs reminder | 232 |
| 5.3.12. Reading | 233 |

| | |
|---|------------|
| 5.3.13. Listening to music | 235 |
| 5.3.14. Multiplication game | 239 |
| 5.3.15. Nao's dance | 243 |
| 5.3.16. Memory game | 245 |
| 5.3.17. Detect person on the ground | 247 |
| 5.3.18. At any time | 251 |
| 5.4. Conclusion | 253 |
| 5.4.1. Nao's limitations and possible improvements | 253 |
| Chapter 6. Application Problems with Solutions | 255 |
| 6.1. Exercise 6.1: car suspension | 255 |
| 6.1.1. Modeling | 256 |
| 6.1.2. Analysis | 257 |
| 6.2. Exercise 6.2: electromechanical system | 259 |
| 6.2.1. Modeling | 260 |
| 6.2.2. Analysis | 262 |
| 6.3. Exercises: identification and state–space representation | 263 |
| 6.3.1. Exercise 6.3 | 263 |
| 6.3.2. Exercise 6.4 | 265 |
| 6.3.3. Exercise 6.5 | 268 |
| 6.3.4. Exercise 6.6 | 270 |
| 6.3.5. Exercise 6.7 | 276 |
| 6.4. Exercises: observation and control of nonlinear systems | 278 |
| 6.4.1. Exercise 6.8 | 278 |
| 6.4.2. Exercise 6.9 | 280 |
| 6.4.3. Exercise 6.10 | 288 |
| 6.4.4. Exercise 6.11 | 291 |
| 6.4.5. Exercise 6.12 | 293 |
| 6.4.6. Exercise 6.13 | 296 |
| 6.4.7. Exercise 6.14 | 300 |
| 6.4.8. Exercise 6.15 | 300 |
| Bibliography | 307 |
| Index | 313 |