Emerging Actuator Technologies
A Micromechatronic Approach

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John Wiley & Sons, Ltd
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To Amparo
and our children
Contents

Foreword xi
Preface xiii
List of Figures xv
List of Tables xxv

1 Actuators in motion control systems: mechatronics 1
1.1 What is an actuator? ................................. 2
1.2 Transducing materials as a basis for actuator design ................................. 5
  1.2.1 Energy domains and transduction phenomena .................... 6
  1.2.2 Transducer basics .................................. 8
1.3 The role of the actuator in a control system: sensing, processing
  and acting ............................................. 11
  1.3.1 Sensing ........................................... 12
  1.3.2 Processing ........................................ 12
  1.3.3 Actuation .......................................... 13
  1.3.4 Impedance matching ................................ 14
1.4 What is mechatronics? Principles and biomimesis ................... 17
  1.4.1 Principles .......................................... 17
  1.4.2 Mechatronics and biomimesis .......................... 19
1.5 Concomitant actuation and sensing: smart structures .............. 23
1.6 Figures of merit of actuator technologies .............................. 27
  1.6.1 Dynamic performance ................................ 28
  1.6.2 Actuator behavior upon scaling ............................ 30
  1.6.3 Suitability for the application ....................... 32
  1.6.4 Static performance .................................. 32
  1.6.5 Impact of environmental parameters ..................... 33
1.7 A classification of actuator technologies ............................... 33
  1.7.1 Semiactive versus active actuators ..................... 33
  1.7.2 Translational versus rotational actuators .................. 34
  1.7.3 Input energy domain .................................. 34
  1.7.4 Soft versus hard actuators ................................ 36
# CONTENTS

1.8 Emerging versus traditional actuator technologies .................. 36
1.9 Scope of the book: emerging actuators ............................... 38
1.10 Other actuator technologies ........................................ 39
  1.10.1 Electrostatic actuators ....................................... 39
  1.10.2 Thermal actuators ............................................. 41
  1.10.3 Magnetic shape memory actuators ............................. 42

2 Piezoelectric actuators ................................................. 46
  2.1 Piezoelectricity and piezoelectric materials ...................... 47
  2.2 Constitutive equations of piezoelectric materials ................ 49
  2.3 Resonant piezoelectric actuators ................................ 51
    2.3.1 Basics of resonant operation of piezoelectric loads .......... 51
    2.3.2 Rotational ultrasonic motors ................................ 57
    2.3.3 Linear ultrasonic motors .................................... 65
  2.4 Nonresonant piezoelectric actuators ............................... 67
    2.4.1 Bimorph actuators .......................................... 67
    2.4.2 Stack piezoelectric actuators ................................ 69
    2.4.3 Inchworm actuators .......................................... 71
  2.5 Control aspects of piezoelectric motors ........................... 72
    2.5.1 Control circuits and resonant drivers ...................... 72
    2.5.2 Control of nonresonant actuators ............................ 79
  2.6 Figures of merit of piezoelectric actuators ....................... 81
    2.6.1 Operational characteristics ................................ 81
    2.6.2 Scaling of piezoelectric actuators ......................... 85
  2.7 Applications .................................................................. 89
    2.7.1 Applications of resonant piezoelectric actuators ............ 89
    2.7.2 Applications of nonresonant piezoelectric actuators ......... 91

3 Shape Memory Actuators (SMAs) ......................................... 101
  3.1 Shape memory alloys .................................................. 102
    3.1.1 The shape memory effect .................................... 103
    3.1.2 Pseudoelasticity in SMAs .................................... 108
  3.2 Design of shape memory actuators .................................. 110
    3.2.1 Design concepts for actuation with SMAs .................... 111
    3.2.2 Material considerations ..................................... 117
    3.2.3 Thermal considerations ...................................... 119
  3.3 Control of SMAs ....................................................... 120
    3.3.1 Electrical heating ............................................ 120
    3.3.2 Concomitant sensing and actuation with SMAs .............. 121
    3.3.3 Integration in control loops ................................ 124
  3.4 Figures of merit of shape memory actuators ....................... 130
    3.4.1 Operational ranges .......................................... 130
    3.4.2 Scaling laws for SMA actuators .............................. 132
  3.5 Applications ........................................................... 133
CONTENTS

4 Electroactive polymer actuators (EAPs) ............................................ 145
  4.1 Principles ................................................................................. 146
    4.1.1 Wet EAP actuators ............................................................ 146
    4.1.2 Dry EAP actuators ............................................................. 155
  4.2 Design issues ........................................................................... 159
  4.3 Control of EAPs ........................................................................ 160
  4.4 Figures of merit of EAPs ............................................................ 163
    4.4.1 Operational characteristics ............................................... 163
    4.4.2 Scaling laws for EAPs ......................................................... 165
  4.5 Applications ............................................................................. 166

5 Magnetostrictive actuators (MSs) ......................................................... 171
  5.1 Principles of magnetostriction ..................................................... 172
    5.1.1 Historical perspective ......................................................... 172
    5.1.2 Basics of magnetic properties of materials ......................... 173
    5.1.3 Magnetostriction: constitutive equations .............................. 175
  5.2 Magnetostrictive materials: giant magnetostriction ....................... 178
    5.2.1 Positive versus negative magnetostriction: effect of the load..................................................... 178
    5.2.2 ΔY-Effect in magnetostrictive materials .............................. 180
  5.3 Design of magnetostrictive actuators .......................................... 181
    5.3.1 Design for improved stroke .............................................. 183
    5.3.2 Design for linearized, push–pull operation .......................... 183
    5.3.3 Design of electric and magnetic circuits ............................. 184
    5.3.4 Design for selected resonance characteristics .................... 185
  5.4 Control of magnetostrictive actuators: vibration absorption .......... 185
    5.4.1 Active vibration suppression .............................................. 186
    5.4.2 Smart actuators and smart structures ................................ 191
    5.4.3 Combined sensing and actuation ....................................... 195
  5.5 Figures of merit of MS actuators ................................................. 197
    5.5.1 Operational range ............................................................. 198
    5.5.2 Scaling laws for magnetostriction ...................................... 199
  5.6 Applications ............................................................................. 200

6 Electro- and magnetorheological actuators (ERFs, MRFs) .................... 205
  6.1 Active rheology: transducing materials ..................................... 206
    6.1.1 Basics of rheology ............................................................. 206
    6.1.2 Field-responsive fluids ...................................................... 209
    6.1.3 Electro- and magnetorheology .......................................... 210
  6.2 Mechatronic design concepts ...................................................... 213
    6.2.1 Shear, flow and squeeze modes ....................................... 213
    6.2.2 Device dimensions according to specifications .................... 216
    6.2.3 Driving electronics for ER and MR devices ....................... 217
    6.2.4 Design of magnetic circuits in MR devices ....................... 221
6.3 Control of ERF and MRF ........................................ 223
  6.3.1 Sky-hook vibration isolation .............................. 225
  6.3.2 Relative vibration isolation .............................. 229
6.4 Figures of merit of ER and MR devices ...................... 229
  6.4.1 Material aspects ......................................... 229
  6.4.2 Size and weight of ER and MR devices .................. 230
  6.4.3 Available dissipative force and power ................... 230
  6.4.4 Scaling of active rheology concepts ...................... 232
6.5 Applications .................................................. 235

7 Summary, conclusions and outlook 244
  7.1 Brief summary ............................................... 244
    7.1.1 Piezoelectric actuators ................................ 247
    7.1.2 Shape memory alloy actuators .......................... 247
    7.1.3 Electroactive polymer actuators ......................... 248
    7.1.4 Magnetostrictive actuators ............................. 249
    7.1.5 Electro- and Magnetorheological fluid actuators ....... 249
    7.1.6 Example applications: case studies ..................... 250
  7.2 Comparative position of emerging actuators ............... 252
    7.2.1 Comparative analysis in terms of force .............. 252
    7.2.2 Comparative analysis in terms of force density ...... 253
    7.2.3 Comparative analysis in terms of stroke ............... 254
    7.2.4 Comparative analysis in terms of work density per cycle 255
    7.2.5 Comparative analysis in terms of power density ...... 256
    7.2.6 Comparative analysis in terms of bandwidth .......... 257
    7.2.7 Relative position in the static and dynamic plane .. 258
    7.2.8 Comparison in terms of scaling trends ............... 261
    7.2.9 Concluding remarks ..................................... 262
  7.3 Research trends and application trends .................... 263
    7.3.1 Piezoelectric actuators ................................ 264
    7.3.2 Shape memory alloy actuators .......................... 265
    7.3.3 Electroactive polymer actuators ......................... 266
    7.3.4 Magnetostrictive actuators ............................. 267
    7.3.5 Electro- and Magnetorheological fluid actuators ....... 268

Bibliography 272

Index 275
Foreword

In recent years, new physicochemical principles and new transducing materials have been discovered, which make it possible to generate mechanical actions that perform the basic functions of an actuator. In today’s world, with increasingly stringent demands for control of widely varying devices, there is a need to find ever more efficient actuators, with more power, bandwidth and precision but smaller in size. This is clearly the case, for example, of actuators for implantation in human beings or for use on space vehicles.

The scientific approaches that the research community has adopted toward the new actuators have been very unfocused and sectoral, as readers will appreciate from the long list of over 50 very recent references dealing with specific aspects that are discussed at the end of this book. This generalized situation of fragmented analysis contrasts with the painstakingly comprehensive and rigorous account, which, here, offers the reader an overview of the subject. Its purpose is to help build up a body of doctrine relating to emerging actuator technologies, and its primary virtue is to treat the various different materials as active or semiactive mechatronic devices so as to be able to integrate them in a controlled system. The actuator itself is considered as a mechatronic system with all its attendant derivatives.

As to the content of the book, this deals systematically with all the principal types of advanced actuators. In methodological terms, each chapter analyzes the principles of transduction with reference to their origin, the materials made, the equations and their characteristics; it then deals with the corresponding control circuits and devotes considerable space to details and novel aspects of applications. Of these, we could mention for example piezoelectric elements for ultraprecise (nm) positioning in grinding machine tools, or shape memory actuators (SMA) for automatic oil-level control in high-speed trains, or, again, magnetorheological fluids (MRFs) for use as active shock absorbers in a lower-limb prosthesis to adapt to an amputee’s gait. In every case, the author provides details of performance and even references to the makers of the actuators described.

The success of this integrated approach is undoubtedly a result of the considerable experience of the author, a prominent member of the SAM (Sensors, Actuators and Microsystems) research group at the Industrial Automation Institute of Madrid (affiliated to the National Science Research Council, CSIC), who has taken part in and directed numerous projects in this area of research and has worked with and at
the most prestigious European and American research organizations and universities. It was his vocation as a researcher that first drew him to so innovative a field and to follow its progress. Conscious of the interest that the theoretical knowledge acquired will attract now and in the future, and also of their practical importance, the author conscientiously explains the most basic ideas clearly and concisely, and moves from there to other increasing complex notions, always highlighting the strengths and weaknesses of these new technologies.

The book commences by presenting the subject of actuators in a general way and explaining their function as a mechanical correcting element in a controlled system. It discusses the dual actuation and sensing functions of certain smart materials, and also the different kinds of actuators, their parameters and the criteria with which they are evaluated.

It then goes on to analyze piezoelectricity as a basis for the development of actuators, both resonant and nonresonant, which react to the application of an electric field; shape memory actuators (SMAs) and the different alloys that possess this ability to actuate when subjected to thermal changes; electro active polymers (EAPs), either ionic or electronic, in which the different effects of the interchange and ordering of matter is especially important; actuators made from electro- and magneto rheological fluids (ERFs, MRFs), whose rheological characteristics vary, depending on the external fields applied; and actuators based on magnetostriction, either positive or negative, where magnetic domains are reoriented by means of an external magnetic field.

Having described their characteristics, the book embarks on an invaluable comparative study of all these actuators, noting the unsolved problems and the latest trends in their resolution. It places particular emphasis on control, on drivers, and, where applicable, on performance or quality standards of actuators. These qualities of the book alone are sufficient to explain its utility to researchers and designers of actuators, or simply to anyone interested in advanced automatic control systems.

If knowledge is the basis of the future, then this book will help us attain that knowledge by furnishing an excellent base from which to embark on new research, development and applications in the vast universe of advanced actuators.

Ramón Ceres

Research Professor, CSIC
Preface

My first contact with the world of new actuators dates back to 1995 when, during a research visit to the Mechanical Department at the Katholieke Universiteit Leuven, Belgium, I was astonished by the elegant and incredibly simple operation of shape memory actuators (they were being applied to biomedical devices). Ever since, I have become acquainted with ever more new types of actuators during research visits to MIT, USA (polymer gel actuators, 1996), TU München, Germany (shape memory actuators, 1997 and 2000), Scuola Superiore di Studi e Perfezionamento Sant’Anna, Italy (micromechatronics of sensing and actuation, 1998 and 1999) and the Department of Cybernetics, University of Reading, UK (magnetorheological actuators, 2002).

These visits and research activities at my home institution made me realize that to be sound an approach to the world of emerging actuator technologies (EATs) must be accompanied by an engineering-based approach that is only realizable if EATs are conceived as true mechatronic systems.

The purpose of this book is to provide an introductory view, with a clear mechatronic focus, of the various different new actuator technologies (piezoelectric, shape memory, electroactive polymer, magnetostrictive and electro- and magnetorheological actuators). It is intended as a reference for mechanical, electrical, electronic and control engineers designing novel actuator systems. The book highlights the concurrent need of all these disciplines for a sound application-oriented approach to the development of new actuators. As such, it covers the principles of actuation, the governing equations, the mechatronic design of actuators and control strategies, their analysis in terms of performance and their behavior upon scaling, and it analyzes the application domains for each technology.

The comprehensive analysis of emergent actuators that this book offers is unique in its scope and in its specific focus on applications, with an unparalleled comparative study of emerging technologies with one another and with traditional actuators.

The book is organized in seven chapters. The first chapter introduces the different concepts and aspects to be considered in the analysis, design, control and application of emerging actuators. Chapters 2 through 5 describe emerging active actuators (piezoelectric, shape memory, electroactive polymer and magnetostrictive actuators respectively) and Chapter 6 describes semiactive emerging actuators (electro- and magnetorheological actuators). Finally, Chapter 7 summarizes the