Preface

Micro/nanorobots and microactuators find their applications in various domains: microUAV in military, microrobots for in-body exploration in medicine, microactuators for microassembly and micromanipulation and for surface characterization with nanometric resolution, etc. In order to reach the severe performances required for these "micro/nano" applications—such as very high resolution, micrometric or submicrometric accuracy, and high bandwidth—convenient design of the actuators and convenient control of them are necessary. Smart materials like piezoelectric and electroactive polymers and flexible structures are among the best candidates to design the actuators, but their characteristics (nonlinearities, badly damped vibrations, etc.) require the use of efficient control techniques. In addition to these characteristics, the particularity of working at the micro/nano-scale (lack of embeddable sensors, high sensitivity to the environment, difficulty to directly sense, general uncertainties on the model used) makes their control even more challenging.

Several researches have been carried out since many years with tremendous success; however, limitations still exist in terms of precision, operating speed, and reliability. Furthermore, emerging and new requirements in micro/nano-scale positioning bring additional challenges for the design and the control of the systems. These challenges include the high axiscoupling in multi-degrees of freedom precise positioning systems, the limitations of the existing sensors to measure the signals in them, the high environmental (thermal, vibration...) sensitivity and the high noise-to-signal ratio as they are more and more small. During these last years, in order to tackle these challenges, advanced design concepts, where some are jointly coupled with control theory to include the performances at the design level, novel sensing and actuation combined technologies, noise measurement and resolution estimation techniques, and advanced control techniques with or without sensors have been developed. Several projects have been launched at the international level for that. Finally, many technical meetings such as workshops and tutorials dealing with the design or with the control of actuators based on smart materials were organized in different international conferences.

This book gives a state of the art of emerging techniques to the characterization and control of actuators based on smart materials working at the micro/nano-scale.

The case of piezoelectric and electroactive polymeric actuators is focused. The book was initiated after a scientific tutorial held during the IEEE—International Conference on Robotics and Automation (ICRA) in May 2011 at Shanghaï, China and organized by the book editor. The tutorial has brought researchers and engineers together to present, discuss, and exchange ideas on the challenging topic: “Dynamics, characterization and control at the micro/nano scale.” The exciting discussions and exchanges between the speakers of the workshop and the audience, composed of engineers, researchers, and students, have resulted in the necessity to make a perennial archive available for a large public of the interesting presentations and discussions. This is the motivation of this book which contains a potential both for industrial applications and for research. The writing of the book is also such that novice academic level (undergrads, masters and Ph.D. students) can start with the domain of the micro/nano-scale and related actuators without difficulty.

This book is composed of twelve chapters that organized into four main parts.

The first part, made of three chapters, concerns the introduction to piezoelectric materials and polymeric materials and their use for the design of actuators working at the micro/nano-scale:

- Chapter 1 deals with the main motivations of using smart materials as a fundamental component in micro/nano-positioning applications. The authors show that actuators based on smart materials are chosen as an alternative to classical actuators, since the design of classical actuated systems is not suitable for the design of very small ones. The chapter particularly gives an emphasis to piezoelectric materials which are widely used in the microworld. Over the chapter, the authors provided the favorable properties of piezoelectric materials which make them very interesting for the design and development of microsystems working at micro/nano-scale.
- Chapter 2 deals with the case of newer polymeric materials as base for actuators. Synthesis of the new materials, modeling, and experimental characterization on these are detailed in the chapter.
- In Chapter 3, a new method to design actuators based on piezoelectric materials is presented. The method uses interval techniques combined with the geometrical and physical model of the actuator. The new technique has an advantage to provide guaranteed performances, thanks to the properties of interval tools.

The second part of the book deals with the closed-loop (or feedback) control of smart materials-based actuators. This part includes four chapters.

- Chapter 4 proposes a decoupling method to model the behavior of a nonlinear and oscillating piezoelectric actuator that has 2-degrees of freedom (2-dof). A robust H-inf technique is afterward employed to control the actuator. Experimental results demonstrate the efficiency of the proposed technique.
- In Chapter 5, a model-based control system to enhance the performances of nano-positioning systems is proposed. Different control methods are applied and they can be classified into: (a) inverse-based control schemes and (b) model-based control schemes.

- Chapter 6 combines interval tools and related techniques with the classical control theory to model a piezoelectric actuator and to synthesize a robust controller for this. The main advantages of the approach are the natural way to characterize parametric uncertainties in the actuator's model, these uncertainties being due to the difficulties of identification and to the high sensitivity of systems working at the micro/nano-scale. The approach also derives low-order controllers which are well appreciated because of their ease of implementation. Finally, the chapter proposes a new way to analyze the performance robustness *a posteriori* by still using interval techniques but combined with the H-inf tool.

- In Chapter 7, a state-feedback control with integral action is introduced to improve the performances of a nonlinear and noisy piezoelectric microsystem. As the state-feedback control requires a linear system, a feedforward controller to compensate the nonlinearity (hysteresis) is first utilized. Furthermore, in order to make the state of the actuator available for the feedback, a Kalman filtering is also proposed. This filtering permits at the same time to reduce the noises seen at the sensor output. The experimental results demonstrated the efficiency of these techniques combined and their interest for micro/nano-positioning.

The third part of the book, made of three chapters, treats the feedforward control of smart materials-based actuators. Feedforward control techniques are very appreciated in systems where the use of sensors is impossible or difficult. In particular, they are of great interest in systems working at the micro/nano-scale due to the lack of embeddable and convenient sensors usable at this scale.

- Chapter 8 presents a hysteresis model based on least squares support vector machine (LSSVM) and proposes feedforward compensators by neglecting the inverse hysteresis. It presents a comparative experimental study to present the advantage of LSSVM over Bouc–Wen Model.
- In Chapter 9, the rate-dependent Prandtl–Ishlinskii hysteresis modeling and control are proposed. The techniques allow to reduce the hysteresis that depends on the rate or the frequency of the input control and that is found in many hysteretic dynamical systems.
- Chapter 10 treats the modeling and the simultaneous feedforward control of the hysteresis, the creep nonlinearity, and the badly damped vibration found in nonlinear and flexible piezoelectric actuators. The design of the three controllers (compensators) for these three behaviors, put in cascade, is based on precise models and on their inversion. The chapter includes experimental results which demonstrate the efficiency of the approach.

The last part presents two of the most emerging topics and applications at the micro/nano-scale: nanorobotics and biological cells micro/nano-manipulation. This part is composed of two chapters.

- Chapter 11 presents the fabrication with nanorobotic techniques and the characterization of piezoresistive force sensors based on helical nanobelts. The process

of fabrication and assembly of the sensors are well detailed and experimental characterization provides their interesting performances.
- Chapter 12 describes computer vision-based sperm analyses and manipulation methods. The chapter also introduces recent progress in automating sperm manipulation procedures, including sperm immobilization, aspiration, and positioning inside a micropipette.

I would like to thank all the contributors of this book who describe new results in a very didactic way in these chapters. Most of the contributors participated in the above-mentioned tutorial. I am also very grateful to Merry Stuber from Springer Verlag for her assistance and encouragement along the preparation of this book. It was a great pleasure to work with her. Finally, I give my thanks to Alison Waldron (from Springer Verlag) to whom I initially contacted for the idea of this book.

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