Introduction

Microrobotics is a recent field that has developed over the last 20 years. Following on from an earlier work published in 2002, *La microrobotique* [BOU 02], and in light of recent results within the field, we decided to write a new book targeted at engineers, students and researchers. This book would present a specific field of microrobotics in greater detail that is specifically involved with the manipulation of micron-sized objects.

Generally speaking, a microrobot is a robot that performs tasks in the microworld – in other words the world of micron-sized objects, also known as micro-objects. A microrobot can:

– manipulate micro-objects, in which case it is known as a micromanipulator.

Although a micromanipulator is not necessarily itself micron-sized, it is generally preferable that it should be small, in particular for reasons of structural rigidity and position resolution. This resolution must be submicron so that it can manipulate and position micron-sized objects. The effector of a micromanipulator must, on the other hand, necessarily be micron-sized, since it is immersed in the microworld, interacting with micro-robjects. All or part of such a microrobot may be based on deformable structures; this avoids the backlash and friction inherent in articulated mechanisms, which, bearing in mind the scale we are working on, are liable to catastrophically degrade the resolution;

– be totally immersed in the microworld, in which case the microrobot itself is micron-sized.

Such robots are generally mobile, able to move in a confined environment (such as within the human body) in order to carry out a task (which might be the transport of micro-objects).

This book very much focuses on the first type, i.e. the manipulation of micron-sized objects, also known as micromanipulation. Given the increasing miniaturization of everyday consumer products, the need for micromanipulation is growing, and in particular for microassembly. Micromechanisms (watches, medical, etc.), microsystems, optics, microelectronics and biology are increasingly in need of efficient and reliable methods of micromanipulation. This book obviously has a bias towards the manipulation of objects by robotic means: inspired by methods that have been tried and tested on macroscopic scales, microrobotics offer the flexibility required in the fabrication of products that have some degree of variability.

Self-assembly, which involves exploiting forces that can cause several micro-objects to position themselves spontaneously at predetermined positions on a surface (making use of long-range forces such as electrostatic forces, or contact forces such as capillary forces), is not within the scope of the present book. This book will concentrate on manipulation by microrobots (which is by nature serial, in contrast to self-assembly, which is parallel but at present still not very flexible).

It should be noted that a microrobot is not necessarily a "MEMS" (*Micro-Electro-Mechanical System*), in other words a microsystem mostly fabricated using microfabrication technologies coming from microelectronics. It may, however, make use of microfabrication technologies, integrating one or more MEMSs, especially for its effectors. If the whole robot is micron-sized, it may itself be a MEMS.

The physical scales discussed in this book span a broad range: the microworld covers the range of 1 μm–1 mm, which is three whole orders of magnitude! It is clear that the physical effects underlying the static and dynamic behaviors involved will vary in strength over such a large range of scales. It is thus important to recognize and understand them as much as possible. Furthermore, many micromanipulation solutions have appeared in recent years that make use of phenomena specific to the scales they operate on. Each solution has its own advantages and disadvantages, but to date no one solution has shown enough clear advantages to raise it clearly above the others. As a result, an understanding of the physics of the microworld is a crucial element of microrobotics, both to understand the behavior of objects on this scale and to appreciate the specific effects used in a given microprehensor. The first chapter of this book describes in detail this physics and the forces involved.

In order to achieve very high positioning resolutions, and consequently very high repeatabilities and precisions, specific actuators may be used, and in particular ones based on active materials such as piezoelectric ceramics, which are currently without question the most widely used material for driving micromanipulators. Chapter 2 presents some of these actuator materials, along with a discussion of guiding with the use of compliant structures.

Generally speaking, the change in the balance of forces involved on the macroscopic scale (where volume-based forces such as weight and inertia dominate) and on the microscopic scale (where surface-based forces such as capillary and electrostatic forces dominate) renders the problem of prehension a particularly delicate one. Chapter 3 therefore discusses microprehensors and micromanipulation strategies applicable in this context.

Beyond the crucial issue of prehension, the scale we are working on also introduces requirements on manipulators. In addition, given that a human cannot directly view the workspace, and cannot feel forces on the microscopic scale, a micromanipulation station must incorporate a vision system and suitable force measurement apparatus. Even if the station is not to be fully automatic, these are crucial for remote operation. All this, along with some elements of control theory, is presented in Chapter 4.

Chapter 5 describes fabrication technologies suitable for microsystems and particularly useful for the fabrication of all or part of a microrobot.

Chapter 6 offers two future directions for micromanipulation:

– further reduction in the scale of the objects to be manipulated, extending the manipulation to nanometer-sized objects. This field of nanorobotics, still in its infancy, is likely to prove an extremely useful complement to the growth of nanotechnologies;

– integration of micromanipulators into a more complete miniaturized production system for microproducts. Such a production system, still very much in the early research stages, is commonly referred to as a microfactory.

Throughout this book, a recurring theme is that of scaling effects. Compared to the macroscopic scale, these introduce a very marked evolution in the dynamics of objects, and require a complete rethink of their function and the techniques used to manipulate them. The three scientific principles underlying this development are:

– knowledge of the dynamics of the microworld, in order to understand it and exploit specific phenomena;

– (micro)mechatronics, for the construction of suitable microrobotic components and structures;

– control of microrobotic systems, and associated perception functions.

We hope that this book, with its detailed review of microrobotics in the sense of robotics for micromanipulation, and its exercises to help the reader understand and master the field, will help engineers, students and researchers to become familiar with this recent field, and to contribute to its development through their scientific and technological work.

Nicolas CHAILLET and Stéphane RÉGNIER