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Edited by Jocelyne Troccaz

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Jocelyne Troccaz

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Introduction

As a physical device endowed with decision-making, perception and action capabilities and connected to the digital world, a robot can intervene in many ways in the context of care.

In a vision closer to the industrial process, the robot – in this case a mobile platform – may contribute to the logistics of a health-care facility by conveying patients and transferring them from the bed to the couch or the operating table. A robot can also serve as an automated transport system for drugs.

Robots can also assist disabled or elderly people. A robotic walker can contribute to keeping an elderly person upright. A fixed or mobile arm, or a humanoid robot can help a disabled person in daily life tasks. A companion that is more or less robotic can act as an assistant for a dependent person. In addition, the robot can be wholly or partially substituted for a defective organ or limb: this includes artificial organs, artificial limbs, prostheses.

A robot can also be a medical or paramedical personnel assistant. For instance, a robotic platform may ease the tasks of rehabilitation staff who help patients to relearn how to walk after spinal cord injuries. An exoskeleton could be used for the rehabilitation of movement after a stroke.

Concerning the more instrumental side of medicine, a robot could hold the "tool" required by the clinician (surgeon, radiologist, radiation oncologist, etc.) to perform a diagnostic or therapeutic gesture. For example, it could perform the machining of a bone cavity for a prosthetic gesture, carry and move a surgical microscope for microsurgery, an endoscope for minimally invasive surgery or a linear accelerator for radiation therapy. A traditional surgical instrument could also be robotic.

It can thus be seen that there are very diverse machines with very different objectives that can be grouped into the "medical robot" term. We will not cover the entire applications spectrum in this book; instead, we will focus exclusively on the "instrument holder" robot or on the "robotic instrument", which concludes this long list. We call this type of device a medico-surgical robot. As will be discussed in more detail later (see Chapter 1), this type of robot was introduced in the early 1980s. It is part of the general theme of "computer-aided medical interventions" (CAMI). CAMI gives clinicians the hardware and software tools to enable them to fully exploit the available multimodal information (prior knowledge, gestures or organ models, medical images, physiological signals, etc.) in order to plan, simulate and perform a diagnostic or therapeutic gesture that is as minimally invasive and effective as possible. This field is thematically wide and relevant to signal and image processing, data fusion as well as modeling and simulation, biomechanics, biomedical engineering or robotics. In this book, we will focus on the aspects related to robotics: design, monitoring/control and the link to medical imaging and human-machine interfaces and evaluation.

The book is organized into 10 chapters:

Chapter 1: This chapter introduces the application domain and the potential contributions of a robot to the achievement of a medico-surgical gesture. The *specifics* of this application domain are introduced and a *state of the art* traces back the evolution of applications, robot types and their mode of control over the last three decades.

Chapter 2: Beyond the scientific and technical aspects developed in this book, the clinical purpose of the described devices complicates the question of their evaluation. Readers with technical training quite clearly imagine the technical validation of a device. More rarely, the reader is faced with the real constraints of clinical application, for instance asepsy in the operating room (but there are many such examples), and also determining the clinical added value of the device with respect to other medical/surgical techniques. This chapter follows the various stages from conception to the use of the system in the routine of clinical practice and presents the key concepts. It provides an ethical and regulatory framework that is useful for the engineers or scientists involved in the design and implementation of a medical robot.

Chapter 3: Medical robotics is basically an *image-guided robotics* since the planning elements of the task are often defined in terms of patient imagery. This imagery can be acquired pre-operatively or intra-operatively. This chapter focuses on the techniques enabling us to link the reference frame "tool" of the robot to the reference frames of patient imagery. It makes extensive use of techniques known as *registration* or matching, which are similar to methods in the field of computer vision.

Chapter 4: Robotic or not, CAMI requires strong interaction with a *non computer expert user* and the human-machine interface is critical. To facilitate the interaction of the user with its system and information rendering in an intra-operative situation, *augmented reality* (AR) aims to present useful information to the clinician (invisible anatomical structures, planning elements, etc.) overlaid with the reality. As in the previous chapter, the link between different reference frames should be determined to allow this overlay. This chapter presents some of the key steps of extracting information on pre-operative imaging, the issue of registering for AR and illustrates the different approaches through examples.

Chapter 5: The specifics of medico-surgical robotics have quickly oriented system designers towards achieving specific robotic systems for an intervention or a type of intervention. The criteria governing the selection of robot architecture are both clinical (type of task, workspace, specific constraints of the asepsis or the compatibility with an imager, etc.) and technical (number of degrees of freedom required, sizing, series/parallel architecture, materials, actuation, etc.). Different *design approaches* that are more or less systematic are presented. The robot has to operate in an environment where human beings are involved, or even move invasive instruments on or within the body (needle, bone cutter, etc.). Safety is at the heart of the design process.

Chapter 6: While Chapter 3 focuses on the issue of linking the robot with an imaging modality (mostly pre-operative), which served for planning via intra-operative data and also to the update this link when it varies during the gesture, this chapter exclusively considers intra-operative imaging used for real-time control of the robot. Although the *visual servoing* is done on the position of a tool or that of an organ the robust and real-time processing of the image is at the heart of the problem. Part of this chapter addresses the issue of imaging. The second part presents the control laws that exploit them. Laparoscopic applications, among other applications, enable us to illustrate the presented approaches.

Chapter 7: Medical robotics is mostly the robotics of *mechanical interaction with living tissues*. When the robot is in contact with these tissues, the force control may therefore turn out to be central for the independent, safe and accurate action of the robot. Similarly, it intervenes in the *physical interaction with a human operator* during tele-surgery (Chapter 8) with force-feedback or comanipulation (Chapter 9). This chapter presents the general context of interaction with the tissues and its modeling, as well as the different types of force control models. A series of examples illustrates these approaches.

Chapter 8: Industrial robotics has accustomed us to the substitution of a human operator with a robot for arduous or repetitive tasks. The complex and highly variable nature of the medical environment, the decision-making required