3rd Summer University in Surgical Robotics, Montpellier, September 05-12, 2007

Abstracts of the lectures

Introduction to surgical robotics
Etienne Dombre

In order to give an overview of the domains covered by Medical robotics, I will first present some R&D projects in assistive technologies and rehabilitation robotics, before focusing on surgical robotics. Then, I will analyze some classical surgical functions ("machining", constrained manipulation, constrained targeting, microsurgery), from the viewpoint of the engineer, in order to illustrate the limitations of the manual procedures. This analysis will serve to justify the introduction of robotics in surgery. The added-values and limitations of computer & robot aided surgery will be discussed. A state of the art will present the main prototypes and commercial systems. Finally, I will list some future directions of R&D and technical challenges.

Computational Models of Human Organs
Olivier Clatz

Decisional processes in modern medicine tend to rely on increasing patient specific data. The number and the complexity of biomedical data acquisition systems raised in the past years. Nowadays, medical acquisition devices especially medical scanners are able to produce a large amount of information, such as high-resolution volumes, temporal sequences or functional images. This new information allows for a more quantitative diagnostic aiming at a personalization of the treatment. However, this growing amount of information tends to be more difficult to analyse by the clinician. In this context, higher-level information such as anatomical and functional models is increasingly required to support diagnosis and treatment. In this tutorial we will present the current research issues towards the precise (patient-specific) reconstruction of virtual models and their functional simulation. We will show different example of computational models of human organs, and how they can be integrated with clinical data in order to provide meaningful and synthesized information to the clinician.

Robot registration
Jocelyne Troccaz

The general problem of registration consists in determining the geometrical relationship between different reference frames where some information is represented. In the context of computer-assisted surgery, this term is most often used when fusing imaging data coming from multi-modality sensors and acquired in different places or at different times. When a robot is introduced, this device also needs to be registered to the data. Indeed, in order to enable the robot to execute a pre-defined plan, or to assist the surgeon in this execution, the relationship between patient data where the planning is defined and the robot reference frame has to be determined. In this talk we present this general context and describe how this problem has been solved for different categories of systems. We distinguish four main intra-operative situations: robot alone, robot plus tracking device, robot plus imaging sensor, robot plus imaging sensor plus tracking device. Several examples are detailed and discussed.

Medical imaging
Christian Barillot

Many research efforts in 3D medical imaging have been directed towards the definition of efficient and fast image processing, matching and visualisation tools. Some very promising results are already available allowing a better access and a better use of the contents of medical images. The objective of this presentation is to give an overview of data fusion paradigm in medical imaging for the purpose of assisting the decision making process. Data fusion facilitates a better use of 3D images by providing methods for 1) the registration of data from multiple modalities e.g., multimodal registration between anatomical and functional data, deformable registration of data from different patients or with a priori knowledge (models and/or atlases) and the recognition of complex anatomical structures and their symbolic identifications, when they are not explicitly described by the image contents. This presentation will focus on the cooperation between registration, segmentation and visualization procedures in medical imaging, with a reminder of the basic assumptions underlying the data fusion concepts and examples coming mostly from the neuroimaging domain.

Real Time Surgery Simulation
Olivier Clatz

The goal of surgical simulation is to provide highly realistic training to increase the diffusion of innovative and less-invasive procedures while decreasing the surgeon's learning curve. Realistic simulators are nevertheless complex software that have to merge multiple scientific domains, often studied independently. In this tutorial, we will present an overview of these different aspects of a simulator: 3D model construction, mechanical properties, contact management, surface and volume cutting, visual rendering, haptic feedback and real time constraint. We will show on a concrete example how these components can be mixed together to achieve a reasonable realism.

Control I: Free space control and interaction control in medical robotics
Philippe Poignet

Medical robots require high performances and robustness for achieving accurate task in interaction with patient such as knee surgery, resection of brain tumors, skin harvesting, MIS…. The capability to handle interaction between manipulator and patient or surgeon is one of the fundamental requirements of medical robots. High performances or interaction are ensured by specific controllers. In the lecture, we will first introduce the basic schemes for free space control (joint space and output space). Then we will focus on interaction control. We will present the classical concepts developed for force regulation. Finally we will exhibit the hybrid external force/position control scheme. The advantages and the efficiency of this scheme will be illustrated on recent applications in reconstructive surgery performed with the SCALPP robot developed at the LIRMM.

Technical I: State of the art and trends for medical robots
Heinz Wörn

Principle definitions and kinematics for surgical robots will be given and illustrated byexamples. The basics for the control of autonomous and teleoperated robots and also the control of a semi-autonomous mode will be presented. Concepts and methods for autonomous medical robots which are currently developed in research projects are described as high precision surgery for cochlear implantation with a parallel kineamatic, autonomous serial robot for bone repositioning, modular medical robot system for autonomous teleoperated and semi-autonomous operations as well as autonomous serial robot for laser ablation.
General research trends for autonomous and teleoperated robots will be presented.

Design and safety
Olivier Company & Sébastien Krut

First of all a general overview of a safety point of view will be done, from the problem statement to a list a safety features. Then a description of main robot arms kinematics will be given, with information on serial, parallel and hybrid arms and their potential use as medical robotics devices will be addressed. This will end with a discussion on the possibility to imagine multi-purpose robot arms for surgery.

Control II: Visual servoing with applications in medical robotics
Jacques Gangloff

The first part of this lecture will be on the fundamentals of visual servoing. After some basic background material, the different architectures for visual servoing schemes (direct vs indirect, position-based vs image-based, ...) will be presented with a comparison of their main features.
The second part of the lecture will present some illustrative examples of minimally invasive medical procedures with robots using visual servoing.

Medical I: Cardiac surgery
Nicolas Bonnet

Applying computer-assisted medical intervention (CAMI) and robotics to cardiac surgery remains particularly complex because of the high quality standard and the many constraints of cardiac surgery. The goal of this lecture is to expose this specific problematic regarding to the minimally invasive techniques and the robotic applications.

After an anatomic and physiological presentation of the cardiocirculatory system, the extracorporeal circulation and the main classical operative techniques in cardiac surgery including minimally invasive cardiac surgery and beating heart surgery will be exposed with video presentation. This part will introduce the robotics techniques used in cardiac surgery with some perspectives.

Medical II: Neurosurgery
C. Bernard

Design and Haptics - Experimental measurements for specification of surgical mechanisms and understanding of surgical skill
Blake Hannaford

This lecture will cover a "bottom up" approach to surgical robot mechanism design. In this approach, we begin by extensive physical measurements of the mechanics of surgery. From this large database, we analyze signal measurements and synthesize requirements. We then repeat the process with candidate robot mechanism designs.

Outline:
I. Surgical Variables and Sensors
 Mechanical Variables
 Force Sensing
II. Instrumented Instruments
 Grasper
 Motorized Grasper
 "Blue Dragon" motion tracker
III. Data Analysis
 Tissue Properties
 Surgical Processes (Hidden Markov Models)
 Motion Range and Kinematics
 Norms and Histograms
IV. Synthesis and Testing of a next generation surgical manipulator
 Port Locations
 Mockup-Testing
 Mechanism Optimization and CAD Visualization
 Design Goals
 Status
 Future Visions

Medical III: Computer assisted orthopaedics surgery
Eric Stindel

Computer Assisted Orthopaedic Surgery is part of the daily routine for some teams since many years. Several thousand of patients have been operated thanks to these innovative techniques in the last 10 years. After a brief history on the introduction of computer assisted surgery into the field, we will focus on the theoretical concepts and technologies on which rely each application. For a better understanding, we will describe the challenges of joint replacement surgery at the knee, and at the hip and explain how bricks of technology and software can be mixed together to answer to these challenges. If the first applications that appeared on the market where clearly dedicated to joint replacement, a second generation of software is now dedicated to soft tissues management. We will describe one of them with its specific challenges and dedicated technological solution: the Anterior Cruciate Ligament replacement. To have an exhaustive overview we will finally focus on the conservative surgery of the knee that may help to prevent joint replacement: High tibial osteotomies are one of them.

For each application we will describe how specific solutions have been developed, and integrated in computer assisted surgical protocols (CAPS). We will discuss validation issues and the notion of clinical accuracy. We will give the pros and cons of each solution based on our personal experience as a developer and surgeon.

Technical II: Real-time active tremor compensation
Wei Tech Ang

Tremor is an involuntary and somewhat rhythmic movement of one or more of the body parts, usually in the hands. There are in general two types of tremor, while pathological tremor is caused by neurological disorders, physiological tremor is inherent to all human beings. This talk discusses how real-time active compensation techniques are used to enhance manual manipulation precision in cases where the signal-to-noise ratio is large, i.e. the amplitude of tremor is in the same order as the task's required accuracy. Two projects will be introduced: (i) Micron - an intelligent handheld instrument for microsurgery; (ii) A wearable orthosis for pathological tremor attenuation.

Technical III: Computer-integrated surgery: coupling information to action in the 21'st century
Russ Taylor

The impact of Computer-Integrated Surgery (CIS) on medicine in the next 20 years will be as great as that of Computer-Integrated Manufacturing on industrial production over the past 20 years. A novel partnership between human surgeons and machines, made possible by advances in computing and engineering technology, will overcome many of the limitations of traditional surgery. By extending human surgeons' ability to plan and carry out surgical interventions more accurately and less invasively, CIS systems will address a vital national need to greatly reduce costs, improve clinical outcomes, and improve the efficiency of health care delivery. As CIS systems evolve, we expect to see the emergence of two dominant and complementary paradigms: *Surgical* ***CAD/CAM*** *systems* will integrate accurate patient-specific models, surgical plan optimization, and a variety of execution environments permitting the plans to be carried out accurately, safely, and with minimal invasiveness. *Surgical Assistant* systems will work cooperatively with human surgeons in carrying out precise and minimally invasive surgical procedures.
The evolution of these systems will be synergistic with the development of *patient-specific surgical simulation* for planning as well as for training and *surgical augmentation* systems transcending human sensory-motor limitations in the performance of surgical tasks. This presentation will use current research at Johns Hopkins University and elsewhere to illustrate these themes and will outline current barriers and opportunities for future developments.

Technical IV: Assistance to gesture with therapeutic applications: understanding human motor control may help
Guillaume Morel

The talk will focus on robotic devices that physically interact with a human operator in order to assist his/her movements. This type of devices is used in the field of surgical robotics, e.g. for augmenting the surgeon force sensing capabilities, removing tremor, preventing the damage of fragile regions, etc. They are also more and more exploited in the domain of rehabilitation, where first clinical results have demonstrated their positive impact on the therapy efficiency.

A major issue in the design of such devices is the control of the interaction with the operator. While, historically, only the behavior of the robot was considered by the engineers (force control, impedance control, passive interaction control, etc.), there is a growing interest in including knowledge about human motor control in the robot controller design. The general goal is to provide intuitiveness and efficiency of the assistance, through the understanding of operator’s intention.
The talk will try to give an overview of this emerging area, with a particular focus on sensing and control problems.

Medical IV: Virtual reality and robotics applied to surgery
Luc Soler

Technological innovations of the 20th century provided medicine and surgery with new tools, among which tele-medicine, virtual reality and robotics are part of the most revolutionary ones. The objective of our research work is to pool these tools so as to create a complete system for support during medical and surgical procedures, ranging from medical image acquisition devices to the interventional robot, including the processing of these images, simulation and augmented reality with associated user interfaces and communication systems. In the near future, thanks to the exploitation of these systems, surgeons will program and check on the virtual clone of the patient an optimum procedure without errors, which will be replayed on the real patient by the robot under surgeon control. This medical dream used to be virtual, but today it is about to become reality. This presentation will illustrate our results in this domain for:

- 3D modelling of patients from their medical image
- Preoperative patient-specific surgical planning
- Patient-specific educative operative simulator
- Preoperative patient-specific operative simulation
- Computer assisted surgery through Automated Augmented Reality
- Surgical gesture automation

Moreover, this presentation will present a new area of research and development in surgery: transluminal endoscopic surgery. This new "no scare" minimally invasive procedure represents today one of the main innovations in surgery and needs computer and robotic assistance certainly more than any previous surgical technique.

Future trends IV: Frontiers of endoluminal robotic surgery
Paolo Dario, Cesare Stefanini

Surgical and diagnostic procedures of the future will evolve from today’s minimally invasive approach to extremely targeted, localized and high precision endoluminal techniques.
This will require an entirely new type of surgical tools, capable of entering the human body through natural orifices (by insertion, ingestion or inhalation), very small incisions (injection), or even through skin absorption, and maybe configuring themselves in complex kinematic structures at the specific site of intervention.
Large robots for minimally invasive surgery (MIS) are already at the clinical stage (e.g. Da Vinci robot by Intuitive Surgical Inc., Mountain View CA, Zeus system by Computer Motion Inc., Santa Barbara, CA) and current research is devoted to integrating the most powerful technologies in terms of imaging, diagnostics tools, etc., into existing systems [Patronik, 2004; Berkelman, 2002; Davies 2002]. These machines are designed to operate in small and delicate workspaces by ensuring high accuracy, reducing the operator fatigue, and levelling

the surgeons’ performance of the interventions. It is unlikely that the present generation of robots for MIS will dominate future surgical practice and, indeed, their use in cardiac, general and visceral surgery is rapidly declining. Based on an extensive analysis of surgical robots reported in [Taylor, Dario, Troccaz, Eds. 2003], it results that the road map goes towards hand-held and endoluminal systems, as demonstrated by recent commercial products in the field of robotic catheters (e.g. Sensei System by Hansen Medical Inc., Mountain View, CA, 2007).

This lecture presents a general scenario of current minimally invasive surgery techniques and the new frontiers of endoluminal surgery in terms of advanced and integrated interventional tools.

- Berkelman, P., Cinquin, P., Troccaz, J., Ayoubi, J., Letoublon, C., Bouchard, F., “A compact, compliant laparoscopic endoscope manipulator”, Proceedings of IEEE International Conference on Robotics and Automation 2002,Vol. 2 , 1870-1875, 11-15 May 2002.

- Davies, B.L., “Robotic surgery: at the cutting edge of technology”, 7th International Workshop on Advanced Motion Control 2002, 15-18, 3-5 July 2002.

- Patronik, N., Zenati, M.A., Riviere, C., “Crawling on the Heart: A Mobile Robotic Device for Minimally Invasive Cardiac Interventions”, Medical Image Computing and Computer-Assisted Intervention, Springer, September, 2004.

- Taylor, R.H., Dario, P., Troccaz, J., Eds., “Special issue: Medical Robotics”, IEEE Transactions on Robotics and Automation, Vol. 19, Issue 5, October 2003.