# 2nd Summer University in Surgical Robotics, Montpellier, September 07-14, 2005

# Abstracts of the lectures

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**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", insertion, minimally-invasive surgery, suturing), 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.

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**Medical Imaging I**
Hervé Delingette

In this lecture, I will present some basic facts regarding medical imaging: quick overview of the different image modalities, the different dimensionalities of images and the main differences between analysis of medical images and video images. Then, I will provide a broad survey of two important class of algorithms used in medical robotics: image segmentation and image registration. Regarding image segmentation, two approaches will be described: classification approaches that are solely based on image intensity information and deformable models approach that combines a priori information about the shape and appearance of the structure to segment. The problem of image registration consists in finding a geometric transformation that associate one image with another. Here also, I will make a distinction between geometric methods requiring the extraction of feature points or lines and iconic methods that rely on the correspondance between intensity distributions.

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**Medical Imaging II**
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. In complement to “Medical Imaging I”, 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.

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**Modeling**
Hervé Delingette

In this lecture, I will present the three different types of computational models of the human body: geometrical, physical and physiological models. The computation modeling of the biomechanics and physiology have especially received a growing interest in the past few years since they take into account phenomena of greater complexity than those solely based on the geometrical description of the anatomy. I will use two examples to illustrate the use of biomechanical models for therapy training and planning: the building of surgical simulators and the planning of neurosurgery. In both cases, one must face the difficulty in modeling the complex behavior of living tissue and to identify meaningful mechanical parameters from indentation tests. Physiological models are of even greater complexity since they include various feedback and coupling phenomena. An integrative model of the electro-mechanical cardiac activity will be presented to illustrate the current research on this topic.

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**Robot registration**
Jocelyn 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.

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**Design and Safety**
François Pierrot

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.

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**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.

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**Control II: Visual Servoing with Applications in Medical Robotics**
Michel de Mathelin

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.

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**Technical I: Applications of force feedback in medical and surgical robotics**
Guillaume Morel

This talk will provide an overview of the current and future applications of force feedback robots for medicine and surgery. Three modalities of "force feedback" will be covered:
1) "Autonomous" force feedback control, which allows for a robot to automously apply controlled forces on a patient ;
2) Force feedback teleoperation, which allows for a surgeon to control a slave robot through master arms, while feeling the forces applied to the patient
3) Comanipulation, which consists for a robot and a surgeon to simultaneously grasp an instrument and "share" its control.
The talk will try to emphasize the potential benefits of the approaches, and the main technical difficulties encountered by the researchers.

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**Technical II: Multidisciplinary Approach in Developing a Minimally Invasive Surgical Robot**
Jacob Rosen

Outline:
- The Operating Room of the Future - The New Vision
- Developing a New MIS Robot Using a Spherical Mechanism
- Kinematics and Dynamics Optimization of a Spherical Mechanism.
- Objective Assessment of Surgical Skill in MIS
- Soft Tissue Biomechanics and Tissue Damage - Experimental Approach

**Technical III: Robot assisted placement of pedicle screws, a “Hands-On-Robotics” approach**
Tobias Ortmaier

This lecture presents a novel system for accurate placement of pedicle screws, developed by the German Aerospace Center. The system consists of a light-weight (< 10 kg), kinematically redundant, and fully torque controlled robot. Additionally, the pose of the robot tool-center point is tracked by an optical navigation system, serving as an external reference source. Therefore, it is possible to measure and to compensate deviations between the intraoperative and the preoperatively planned pose. The robotic arm itself is impedance controlled. This allows for a new intuitive man-machine-interface as the joint units are equipped with torque sensors: the robot can be moved just by pulling/pushing its structure (i.e. haptic interaction, hands-on-robotics). The surgeon has full control of the robot at every step of the intervention. The hand-eye-coordination problems known from manual pedicle screw placement can be omitted.
The presentation gives an overview on:
- Medical application and medical workflow
- Kinematic design of the robot
- Robot hardware (including joints and joint sensors, communication between joint units)
- Robot control
- Outlook and future development

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**Technical IV: Real-time Active Tremor Compensation in Microsurgery**
Wei Tech Ang

This lecture introduces the research and development of an intelligent handheld instrument for real-time active tremor compensation in microsurgery. The instrument senses its own movement, distinguishes between the intended and erroneous motion, and deflects its tip in real-time to cancel the tremulous component. This lecture covers the following topics:
1. Quantification of physiological tremor in microsurgery
2. Micro-sensing of instrument motion
3. Zero-phase filtering of erroneous motion components
4. Design and control of piezo-driven intraocular shaft micromanipulator

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**Medical I & II: Cardiac surgery**
Nicolas Bonnet & Olivier Chavanon

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 (NB), 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 (OC). This part will introduce the robotics techniques used in cardiac surgery with some perspectives (NB). To conclude, an example of CAMI applied in this field of soft tissue will be exposed with the computer-assisted pericardiocentesis system (OC).

## Medical III: 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 revolutionizing ones. The objective of our research works 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.

Today, diagnosis support systems that have thus been developed allow to model patients in 3D from their CT-scan or MRI (figure 1). Practitioners can so plan the surgical intervention and decide over the best treatment to apply. From this virtual patient clone, it is then possible to practice on simulators before carrying out the surgical manoeuvre, thus imitating simulation techniques that are accepted and recognized in aeronautics. As for the latest simulator for ultrasound guided procedures we have developed, one of the major assets of all these preoperative systems is to run on low cost standard multimedia computers. This way, a fast spreading of such a concept in hospitals can be considered.

Thanks to the use of the preoperative step of virtual reality during the intervention, it is furthermore possible to provide a new view of the patient in virtual transparency. This new vision, called “augmented reality”, consists in superimposing the virtual image of the patient onto the video image that is realized during the intervention (figure 2, JAMA November 2004). During the intervention, augmented reality therefore offers surgeons a view in transparency of their patient, what tomorrow will lead to the automation of the most complex manoeuvres. This automation necessarily requires the exploitation of surgical robotics, the latest major axis of our works. The surgical operation carried out in 2001 from New York by Professor Marescaux on a patient in Strasbourg is certainly the most spectacular result, illustrating the possibilities of robotics. In partnership with the University of Strasbourg, we have developed since then new robotic systems that allow the automated control of the robot, in particular by filtering heart beat movements automatically.

In the near future, thanks to the exploitation of these systems, surgeons will program and check on the virtual clone of the patient an optimal 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.

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## Medical IV: 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.

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**Industrial I: Computer assisted dental implantology from Research to Industry**
Guillaume Champleboux

10 years ago, a new process for computer assisted dental Implantology has been created by researchers of the Grenoble University. Prior to this development, dental implants were placed directly into the bone under direct visualization after the gum is cut and folded back to expose the bone.
This new process now diffused by the CADImplant Company involves computers, software and a part of robotics. The CADImplant software program is used by the dentist on an office or laptop computer to pre-plan the exact placement of the patient's implants based on the patient's CT scan of the jaw. The CT scan is taken with the patented CADImplant "Reference Cube" to correlate the CT with the software and ultimately with the pre-surgical drilling of the patient's surgical guide. CADImplant Inc drills the surgical template according to the software planning made by the dentist. The pre-drilled guide now permits the patient to have implants placed directly thru the gum and into the bone without opening a gum flap. CADImplant allows the oral surgeon and the dentist to place implants with less pain and obtain a more predictable result.
This lecture will describe the problem of placing dental implant and the solution that has been first technically validated, and then clinically validated.
We will describe all the steps beginning from the research state of art and ending with the industrial product.

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**Industrial II: Evolution of surgical navigation during past decade**
Yves Patoux

Surgical navigation has greatly evolved during the past decade, in terms of localization technologies as well as in terms of registration techniques, imaging modalities, patient data management, OR equipments interfacing, but also and mainly surgical applications.
Initially based on navigation principle, Surgical Robotics also entried the O.R 10 years ago (~). During this decade, two major orientations were taken: Automatic tool positioners and Remote Instruments manipulators.As for navigation, number of specialties now use or intend to use robots as additional accurate surgical tool in the O.R. environment
This presentation will briefly overview the different systems and their applications.

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**Future trends I: Computer-Integrated Surgical System**
Masoru Mitsuishi

In my talk, I will introduce the following systems: (1) a neuro-surgical system which operates in the deep surgical field of the brain and can suture a blood vessel with a diameter less than 1 mm, (2) a remote, minimally-invasive, surgical system with a link- driven, multiple d.o.f. forceps and an augmented force display that can be used to prevent the application of excessive force during surgery, (3) a minimally invasive bone cutting system for use in the fitting of artificial joints, and (4) a bone fracture reduction system which provides an image-guided environment for accurate reduction with limited medical staff. Other investigations related to these systems will be also introduced in the lecture.

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**Future trends II: Computer-Integrated Surgery: Coupling Information to Action in the 21'st Century**
Greg Hager

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.

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**Future trends III: From Computer Assisted Medical Interventions (CAMI) to Quality Inspired Surgery**
Philippe Cinquin

First generation of research and industrial development lead to successful introduction of Information Technology (computers, navigation devices, robots, …) in the Operating Room. It can now be proven that such techniques significantly enhance the clinical outcome of surgical procedures. To go further on this road towards Quality, the challenge now is to "invert this movement": instead of moving the computer in the Operating Room, we should embed the surgeon (or at least his or her expertise) into the IT-based tools he or she uses. Taking up this challenge implies a major renewal of the currently available set of knowledge and expertise. This will replace Quality (in its medical meaning) at the heart of the process of combining surgery and informatics. Models of various types will need to be developed and used to achieve a global vision of the therapeutic process, on the basis of which Quality Inspired Surgery could be designed and performed.

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**Future trends IV: Frontiers of Endoluminal Robotic Surgery**
Paolo Dario

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.

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.


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- *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.*