4^{th} Summer University in Surgical Robotics, Montpellier, September 09-16, 2009

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, surface tracking, 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.

Medical I: NOTES
Monika Hagen

Natural orifice transluminal endoscopic surgery (NOTES) is an emerging experimental alternative to conventional open and laparoscopic surgery. NOTES eliminates abdominal incisions and incision-related complications resulting in potentially less invasive and cosmetically superior results. Since the first NOTES experiment was reported by Kalloo et al. in 2004, significant achievements in the laboratory have occurred. Clinical use in humans has been limited and remains a domain of designated centers: transvaginal and transgastric surgeries for gallbladder removal, appendectomy, gastric sleeve resection, nephrectomy, hernia repair and others have been reported. At present, clinical NOTES is conducted by combining endoscopic and laparoscopic techniques, but technological advance is needed for better solutions in regards to safe access, installations and maintenance of pneumoperitoneum, organ retraction, ensuring a stable operating platform, closure, etc. Different solutions are being presented mainly as prototypes by various surgical device companies. Pace of developments replaced initial sketism by optimism and NOTES might act as an important factor in reducing operating trauma in the field of minimal invasive surgery.

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.

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: Urology applications
Jocelyne Troccaz

Urology concerns the uro-genital apparatus of men and the urinary apparatus of women. Over the last decade, many attention has been given to the development of computer-assistance to this clinical domain. In this talk, we will focus mainly on prostate and kidney applications and will give example of systems developed and work in progress. Prostate applications include trans-urethral resection, radical prostatectomy, biopsy and brachytherapy - both diagnostic and therapeutic interventions. Kidney applications mostly concern percutaneous access to the kidney. As will be seen in the examples coming from the large literature, most robots are connected to imaging (very often ultrasound but also MRI and CT imaging).

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: Dynamic visual servoing for surgical robotics
Jacques Gangloff

Visual servoing is the control of an actuated mechanical structure using visual feedback. A

distinction is made between kinematic and dynamic visual servoing. The first approach uses some assumptions that hold only for slow motions. Its main advantage is simplicity. Dynamic visual servoing relies on a more complex model of the visual loop including all the dynamic effects (manipulator and vision system). The better the accuracy of the model, the larger the bandwidth of the visual loop.
In this lecture, the basic notions used in visual sevoing will be introduced. Then, a more detailed explanation on the differences between kinematic and dynamic visual servoing will be given. Finally, the focus will be put on dynamic visual servoing and some examples of control schemes used in surgical robotics applications will be discussed.

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 imaging (Basic)
Guang-Z. Yang

In this lecture, we will discuss the basic principles of key medical imaging modalities including ultrasound, CT, MRI and PET/SPECT and outline the current trend of imaging being increasingly moving from a primarily diagnostic modality towards a therapeutic and interventional aid, facilitated by advances in minimal access and robotic assisted surgery, along with the emergence of novel drugs and other forms of treatment.

Medical imaging (Advanced)
Guang-Z. Yang

This lecture will focus on the latest development of real-time adaptive imaging techniques for in situ, in vivo surgical guidance. We will use intra-operative MRI and biophotonics as examples to demonstrate how such modalities can be integrated with the current surgical workflow, particularly robotic assisted MIS. Issues related to multi-scale integration, image guided navigation and augmented reality (particularly the concept of inverse realism) will be discussed.

Technical II: Integration of Robotics and Biomedical Measurements for Computer Aided Surgery
Ishiro Sakuma

Intra-operative imaging devices such as CT and MRI are installed in an operating room. They provide detailed anatomical structure of surgical field and enable image-guided operation. There are still limitations of temporal and spatial resolution in the data acquired by these devices. There is also demand for functional information that provides pathological information of patient tissue. Thus, it is required to integrate various types of information obtained by biomedical measurements and those obtained by intra-operative imaging devices. Examples of these devices are an electrophysiological recording system and a spectrophotometric measurement device. These measurement devices should have function to determine their three-dimensional position relative to the patient in addition to their main measurement information when they are integrated in image-guidance system for surgery. Integration of advanced surgical instruments such as surgical robots is also being investigated. As one example of such integration, we integrated an intra-operative fluorescence detection system and laser ablation system.
5-ALA is natural chemical substances found in human body that is accumulated in brain tumor ;arger than in normal tissue. 5-ALA induced Pp9 is produced intracellularly and accumulates selectively in tumor cells. When patient with brain tumor administers 5-ALA before surgery, tumor fluorescence around 635[nm] is observed with excitation light around 405[nm]. The 5-ALA induced fluorescence detection system can be also integrated with a surgical navigation system. The fluorescence spectra can be registered to the corresponding location in surgical navigation map. The surgeon can utilize both anatomical information and functional information coming from tissue fluorescence. A surgical laser ablation system can be controlled by intra-operative fluorescence information.
Control of Surgical robots by combination of intra-operative physiological/pathological information together with three dimensional medical image information enables precise positioning of surgical device to the target area leading to minimally invasive target therapy.

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.

Medical II: Image-guided Minimally Invasive Robotic Surgery
Makoto Hashizume

Surgical robotic systems are now making exceptional progress in the field of minimally invasive surgery mainly because robotic surgery has overcome the technical difficulties in endoscopic surgery. The number of installation of the most popular surgical robotic system, da Vinci, is more than 1,000 over the world. The robotic surgery has been applied to almost 70% among the all patients who underwent the prostatectomy in the United States, while it is still limited to the specific surgical field in some countries.
Robotics allows the surgeon to work at a distance from the operating table in an ergonomically correct position, instead of having to bend awkwardly above the patient. The surgeon's movements are transmitted to the computer at the patient's side. These movements are actually improved by the computer. This technology made it possible to operate on a patient under a remote control with tele-robotics. We have successfully performed remote robotic surgery on a soft cadaver by using the recently developed endoscopic robot between Bangkok and Fukuoka.
Virtual and augmented reality systems can be used not only to teach surgical skills, but also to rehearse procedures before performing them. As surgical simulators become more perfected in the near future, surgeons may work out the best operative procedure for each patient and be able to repeat individual steps to improve the surgical technique. Combining augmented reality with advanced robotics could guide surgeons through technically challenging procedures and help avoid injury to vital structures.
We have recently developed a new prototype of the MRI-guided surgical robotic system. The system consists of master-slave manipulators, tele-robotic system, MR-compatible endoscope system, open MRI and integrated image controller. The robot has four arms; one is for holding the endoscope and the other three are for holding interventional and endoscopic surgical instruments. A newly developed intra-operative MRI-guided surgical robotic system was useful to provide safer and more precise procedures in MIS. This technology provides possibility of a mobile operation room with a small-sized surgical robotic system.
Robotic and computer-aided surgical systems offer a new paradigm for the 21st century for information transfer and operating room integration. What we need in revolution of surgery is a mind of challenge and practice rather than knowledge.

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 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.

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.

Future trends in surgical robotics: Frontiers of endoluminal robotic surgery
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.*

Technical IV: Robotics and allied technologies in surgery: medical and market perspective
Marc Schurr

Future trends in surgery:
Alfred Cuschieri

The presentation will cover:

i. The development of robotic master slave manipulators (MSM) specifically for various operations with emphasis on those interventions which benefit in terms of ease of execution and patient outcome from the use of such technologies as distinct to hand execution for both traditional open and minimally invasive surgical approaches.

ii. The disadvantages of the current state of the art systems exemplified by the 4-arm Da Vinci system (Intuitive Surgical) which include operational costs, distancing of the surgeon from the patient and crowding of the operating room space.
iii. How these disadvantages can be overcome by the next generation of robotic MSM envisaged by the European ARAKNES project under development
iv. Alternatives to robotic MSM - hand held MSM with 6 degrees of freedom which can be considered as low-cost alternatives for executing complex surgical tasks such as suturing, exemplified by the Radius system(Tuebingen Scientific) and the DARES system developed by the engineers at the Institute for Medical Science and Technology.

Likely evolution of minimal access surgery aimed at abolition/ reduction of skin incisions by interventions through natural orifices including the umbilical pit and the need for future robotic and hand-held MSM to be capable of deployment through these newer laparoscopic approaches.

Simulation and haptics
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.

Technical V: Assistance to gesture with therapeutic applications: the comanipulation concept
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 focus, on a first part, on applications of comanipulation to surgery, and, on a second part, on some of the fundamental problems and associated design and control issues.
