SURGICAL ROBOTICS
MONTPELLIER FRANCE 2017
8th Summer School

LIRMM

8th Surgical Robotics Summer School Abstracts

- SSSR 2017 -

Philippe Poignet, LIRMM, Montpellier, France

- **Title**: Introduction to surgical robotics
- **Abstract**: 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.

Nabil Zemiti, LIRMM, Montpellier, France

- **Title**: Control in medical and surgical robotics
- **Abstract**: 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.

Jocelyne Troccaz, TIMC, Grenoble, France

- **Title**: Robot registration
- **Abstract**: 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 intraoperative situations: robot alone, robot plus tracking device, robot plus imaging sensor, robot plus imaging sensor plus tracking device. Several examples are detailed and discussed.

Nassir Navab, TUM, Munich, Germany

Christian Duriez, INRIA, Villeneuve d'Ascq, France

- **Title** : "Real-time haptic simulation of medical procedures involving deformations and device-tissue interactions”
- **Abstract**: In this work, we aim to provide new simulation tools for medical and surgical interventions. These tools have many applications including training of physicians, planning of interventions, providing assistance during a real intervention or for the control of surgical robots.

  However, to obtain a realistic or even predictive simulation of the procedure, we must take into account the deformation of the anatomical structures and the mechanical interactions between devices and tissues. At the same time, the simulation must be interactive and computed in real-time to keep the gesture of the physician in the loop of the simulation. The major challenge of our work is to guarantee a certain level of accuracy in the simulation while keeping a very short computation time, consistent with the real-time.

  This lecture will introduce the scientific issues and some recent results: algorithms and models to simulate the deformations of the anatomical structures with finite element method, models for the simulation of the tool-tissues interactions, and the approaches dedicated to haptic rendering of surgical simulation. The open-source SOFA framework (www.sofa-framework.org) dedicated to interactive medical simulations will also be presented. Finally, some preliminary work on the use of simulation for helping the robotization of a procedure and for the control of soft-robots will be shown.

Sylvain Martel, Polytechnique Montréal, Canada

- **Title**: Medical nanorobotics for cancer therapy
- **Abstract**: The implementation of actuation-navigation-sensory capabilities required for medical artificial nanorobotic agents to enhance targeting and the therapeutic efficacy for treating cancer is still far beyond present technological feasibility. Since the implementation of these essential functions remains a great challenge at such a scale and within such an environment, medical nanorobotics also consider natural microorganisms such as specialized bacteria to implement such advanced functions. Presently, hundreds of millions of MC-1 bacteria are being harnessed simultaneously to mimic swarms of such futuristic artificial nanorobots with an equivalent capability level when operating in a computer-controlled artificial environment enabling the exploitation of their magneto-aerotactic migration behavior. The presentation will describe such approach and how complementary technologies can extend further the types of cancers that could be targeted.

Florent Nageotte, ICube, Strasbourg, France

Title: Vision-based control of robots – Application to medical robotics

Abstract: Vision-based control of robots consists in using an imaging device as an external sensor for controlling the position or the motion of robots end-effector in real-time. This technique, also called visual servoing, is attractive because of its similarity with the way human-beings control their hands for reaching and moving objects. The interest for this kind of control has begun in the 1980's and a unifying framework has been developed at the end of the 1980's and during the 90's.
Since then, visual servoing has become an important field of robotics and has generated hundreds of papers, with various goals such as improving stability, trajectories or robustness.
Vision-based control has been used in many medical applications, where visual sensors are usually the main available sensors. To this day most of these applications have remained at the research stage. However, vision-based control should play an important role in the future in this field.

In this lecture I will first present the basics of visual servoing including the two most common approaches, namely Position-based visual servoing (PBVS) and Image-based visual servoing (IBVS). I will try to emphasize the practical limitations and issues encountered when working with standard cameras and with other imaging devices used in medical applications.
Then I will give a quick overview of some improvements on different interesting aspects, such as the use of complex image features or working with unknown targets.
All along the talk, we will look at some of the existing applications in the field of medical robotics (laparoscopic surgery, heart surgery, needle insertions, ultrasonographic examination, flexible endoscopy) and discuss their current limitations.

Silvana Perretta, IRCAD, Strasbourg, France

- **Title: Surgery 4.0: revolution in the O.R**

- **Abstract** The last decade has seen a radical change in how we perceive and practice surgery. We are witnessing the crux of another grand evolutionary step, akin to laparoscopy in the 1990s. There is a strong movement away from practice specific approach to disease care and a new mandate that care should be patient specific, personalized and value based. In the field of surgery this means that traditional practice silos, like surgery, interventional radiology and medical endoscopy, are no longer pragmatic, patients friendly or economically viable. The emphasis is, and should be, on patients customized approaches that use all the available tools and technology providing care that maximizes outcomes while minimizing patient impact namely complications, pain, and life disruption.

Christos Bergeles, University College of London, UK

- Title: Inferring robot and tissue geometry from medical images
- Abstract: This talk will present a variety of methods to reconstruct and track the 3D structure of tissue from endoscopic videos, and reconstruct the shape of intraluminal robots from fluoroscopic images. We will start with monocular camera systems and fundamental structure-from-motion approaches, and proceed to consider multi-view 3D reconstruction from stereo camera streams. We will consider light-field imaging technology and its potential applications into medical imaging, and touch on the concepts of generalised cameras. The talk will proceed with pose estimation of laparoscopic instruments from endoscopic videos, as well as flexible robots from fluoroscopic videos. We will conclude with an overview of upcoming techniques and algorithms that utilise multispectral information, and an overview of upcoming robotic applications that will be the playfield for image-guidance algorithms.

Andreas Melzer, IMSaT, Dundee, UK

- **Title**: Robotics for Image guided Procedures (to be confirmed)

- **Abstract**: "Many different robotic systems have been developed for surgical procedures over the past 25 years. Medical robotics for image guided procedures is an evolving field and the ultimate role of these systems has yet to be determined. This presentation will focus on robotic systems for image guided interventions such as biopsy of suspicious lesions, drainage interstitial tumor treatment or needle placement for pain treatment, spinal blocks and neurolysis. Historian remarks will include the early work on CT guided stereotactic brain procedures XRay and Ultrasound guided robotics and the first MRI compatible mechatronic devices. Five interventional robotics systems designed to work with MRI, CT, fluoroscopy, and ultrasound imaging will be presented and compared in more detail. The systems include the AcuBot for active needle insertion under CT or fluoroscopy, the B-Rob systems for needle placement using CT or ultrasound, the Innomotion for MRI and CT interventions, the MRBot for MRI guided prostate procedures and ExAblate MR guided Focused Ultrasound . Following the systems descriptions, the issues of imaging system compatibiliy for the kinematics, sensors and drives, registration needs, patient movement and respiration motion compensation, and the potential for force feedback, and control mode will be discussed. Further research and clinical trials requirements will be outlined."

Jaydev Desai, Georgia Tech, Atlanta, USA

Title: Flexible Meso-scale Robotic Systems for Image-guided Neurosurgery (to be confirmed**)**

Abstract: This talk will focus specifically on two areas within image-guided robot-assisted neurosurgery, namely: a) MINIR: Minimally Invasive Neurosurgical Intracranial Robot and b) Neurosurgical Intracerebral Hemorrhage Evacuation (NICHE) robot.

Brain tumors are among the most feared complications of cancer occurring in 20–40% of adult cancer patients. Though there have been significant advances in treatment, the prognosis of these patients is poor. Whether there is a primary malignancy or a secondary malignancy, whenever the brain of the cancer patient is involved in treatment, there is a significant impact on their overall quality of life. While the most optimal treatment currently for most brain tumors involves primary surgical resection, many patients may not be able to undergo that treatment plan due to either their poor general health or an unfavorable location (either deep inside the brain or inaccessibility of the tumor) of the lesion. Hence, this is a significant healthcare problem. Similarly, spontaneous intracerebral hemorrhage (ICH) occurs in about 2 million people worldwide. The 30-day mortality rate is about 32-50% and functional independence after 6 months is achieved in only about 20-25% of the individuals who survive such hemorrhages. Removal of the blood clot and decreasing the recurrence of re-hemorrhage using robotic techniques could potentially help with effective management of ICH. In both cases, traditional approaches are limiting, since they do not provide visualization beyond the direct line-of-sight.

This talk will focus on our progress on the development of flexible meso-scale image-guided robotic systems for these two National Institutes of Health (NIH) funded projects involving innovative design of the robots and the associated kinematics, magnetic resonance imaging (MRI) compatible actuation, adaptive backbone stiffening of the flexible robot, and evaluation of these systems under the appropriate imaging environment.

Jessica Burgner-Kahrs, LKR, Leibniz Universität Hannover, Germany

- **Title:** Perspectives of Continuum Robots in Surgical Applications
- **Abstract**: Continuum robots are not composed of discrete joints or rigid links and thus differ substantially from conventional robots. Their structure is inspired by nature, in particular by the animal kingdom, e.g. elephant trunks, snakes, or tentacles. Continuum robots are composed of flexible, elastic, or soft materials such that they can exhibit complex bending motions. The high scalability and miniaturization potential allow for numerous macro- and microscale applications, such as dexterous manipulation in constrained environments e.g. minimally invasive surgery through natural orifices. The presentation will give an overview on continuum robot designs and touch upon fundamentals in kinematic modeling, planning and control. The merits of continuum robotics in surgery are discussed for several example applications and open research questions and challenges are elaborated.

Brian Davies, Imperial College London, UK

- Title: Robotic Orthopaedic Surgery: where have we been and where are we going?

- Abstract: Robotic Orthopaedic Surgery first started clinically in 1992 with the Robodoc system. Since that time many new systems have been clinically applied and these will be presented together with illustrations. The potential benefits and difficulties will be discussed. More recent trends towards simpler systems, applied in a range of Orthopaedic applications, will also be illustrated. The authors experience in a number of spin-out activities will be presented together with a discussion of the merits of starting a SME as a result of your research. Some predictions about the trends over the next few years will also be given.

Eric Stindel, CHU-LATIM, Brest, France

Cameron Riviere, Carnegie Mellon University, USA

- **Title**: Compensation of physiological motion for enhanced surgical accuracy

- **Abstract**: Involuntary quasi-periodic physiological motion hinders accurate manipulation during surgery. The problem in some cases is motion of the patient (e.g., heartbeat, respiration), in others, motion of the surgeon (e.g., hand tremor). Accuracy can be improved by robotic compensation of the physiological motion. This talk will describe active and passive techniques for compensation of all of the above disturbances, enabling more accurate tool positioning and thereby reduced collateral damage to tissue. The talk will review relevant research in the field, and will highlight related research in the Surgical Mechatronics Laboratory (SML) of the Robotics Institute at Carnegie Mellon, including Micron, which performs active compensation of the physiological hand tremor of microsurgeons, and HeartLander, which performs passive compensation of heartbeat and respiratory motion for accuracy enhancement in cardiac surgery.

Sarthak Misra, University of Twente, The Netherlands

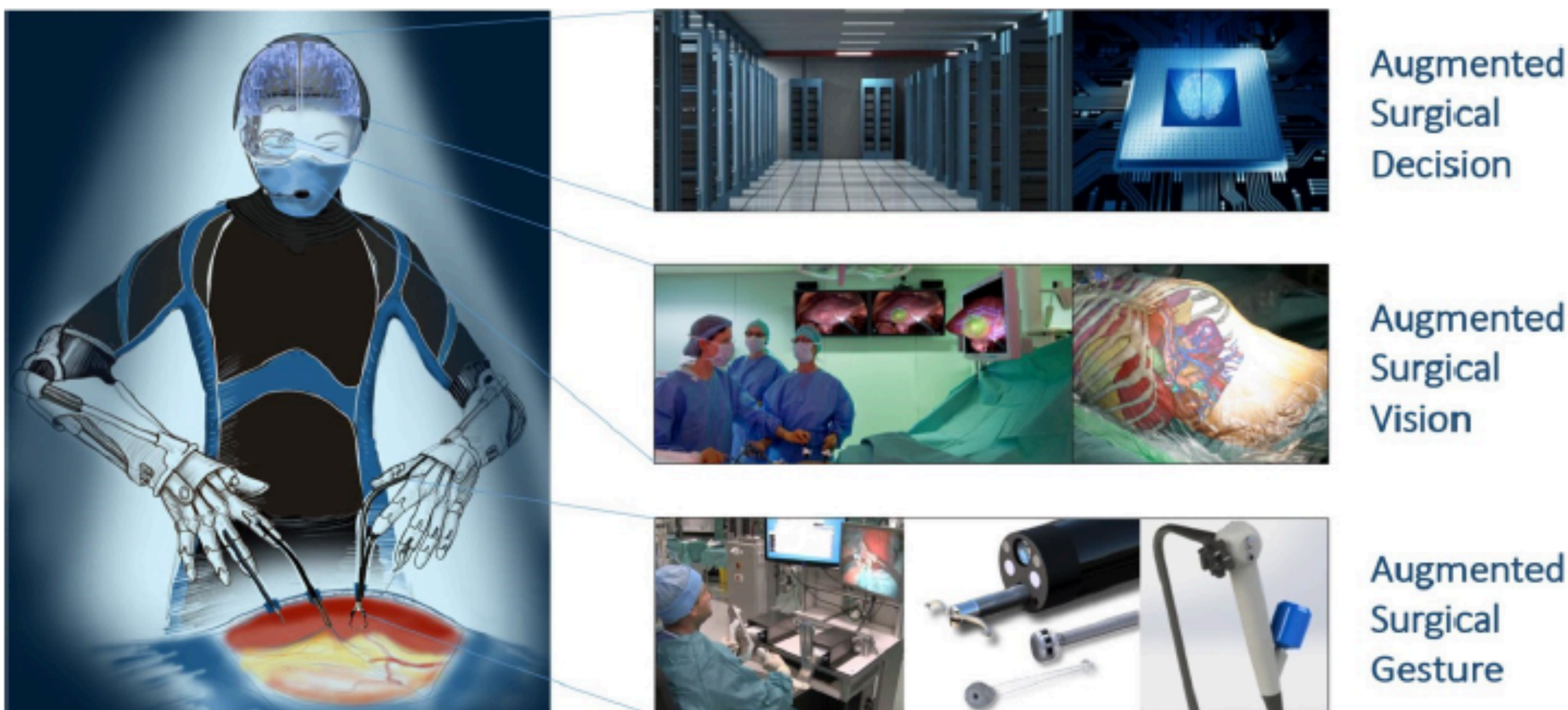
Title: Targeted Drug Delivery Systems: Needle Steering and Medical Microrobotics

Abstract: The talk provides an overview of two ongoing research topics within the Surgical Robotics Lab in the area of targeted drug delivery systems, i.e., needle steering and medical microrobotics. In the first part of the talk, I will combine needle deflection models with image-guided techniques to steer flexible needles to a moving target. Two different models for predicting needle deflection undergoing multiple bends are presented. The first is a kinematics-based model, and the second model predicts needle deflection based on the mechanics of needle-tissue interaction. The models are validated using double bend experiments in soft-tissue simulants, and also using a needle embedded with Fiber Bragg Grating sensors. The kinematics-based model is used for steering the needles under image-guidance. The proposed steering algorithm is demonstrated using camera and ultrasound images as feedback while compensating for target motion. The algorithm is also used to track a needle undergoing multiple bends in 3D using a 2D ultrasound probe. In the second half of the talk, I will discuss how wirelessly controlled agents might offer advantages in terms of reduced invasiveness and untethered access to deep--seated regions within the human body. On that account, this talk covers the closed-loop control of microparticles, magnetotactic bacteria, microjets, and magnetosperms.

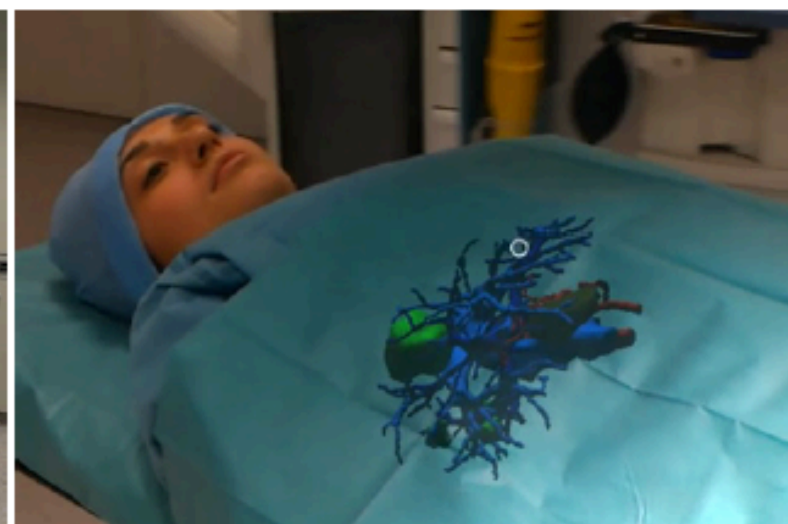
Luc Soler, IRCAD, Strasbourg, France

- **Title:** Computer assisted Minimally invasive Hybrid Surgery

A new surgery area is rising: the Augmented Surgery. Indeed, over the last years, several new computer-assisted surgery technologies have been developed in order to improve surgeon ability and increase safety. These technologies augment surgeon vision, surgeon gesture and surgeon decision, introducing the Augmented Surgery concept.

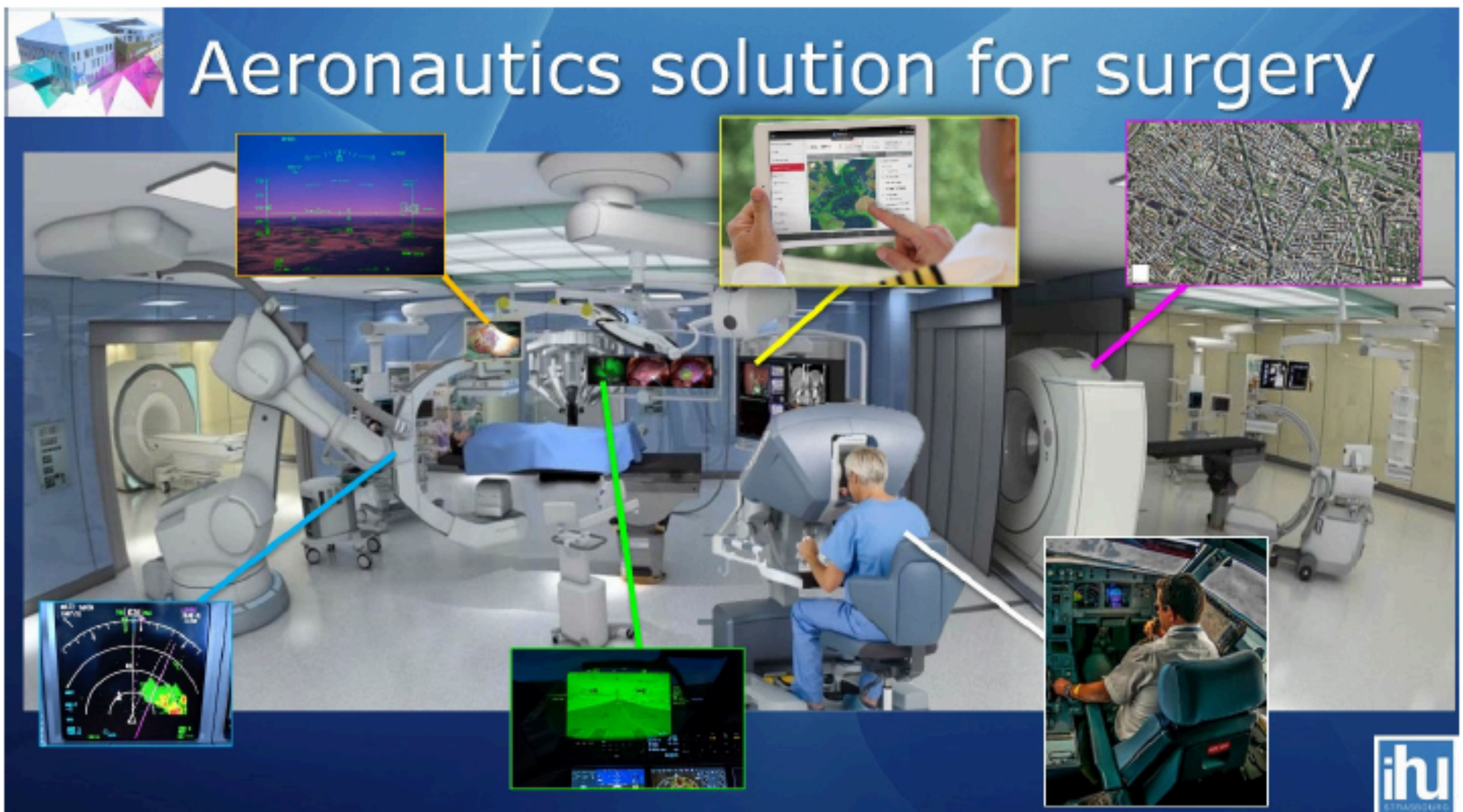


Augmented surgical vision is based on 3D/4D patient-specific modelling. The first step consists in the 3D delineation of organs and pathologies from a patient's medical image (CT or MRI). Such delineation is provided online to the surgeon thanks to the Visible Patient Service. This delineation is then used to realize a 3D model, which is a kind of virtual clone of the patient. Preoperatively, this clone can be used to plan the surgical procedure in the most efficient way thanks to user-friendly Virtual Surgical Planning software working on smartphone, tablet or personal computer. This virtual preoperative simulation allows for the definition of the most efficient therapy to be applied thanks to a perfect localisation of the pathology and surrounding vascularisation. Intraoperative assistance will then consist in superimposing this surgical planning onto the surgical view. This fusion between real vision and virtual model is called Augmented Reality and provides a kind of virtual transparency of the patient. Main limits of this technique are linked to organ movement and deformation between the preoperative image and the intraoperative position and shape. To overcome this limit, the introduction and use of 3D-medical imaging systems in the Operating Room is then mandatory. The resulting Hybrid OR is thus equipped with MRI, CT or/and 3D C-ARM such as the Artis Zeego from Siemens providing a 3D image of the patient after only 5 seconds of acquisition.



The 3D intraoperative medical image is then registered with the preoperative image in order to correct organ deformations. Thanks to the laparoscopic image analysis, it is possible for a computer to compute in real-time the precise location and shape of organs and pathology. This information can then be combined with a robotic system in order to develop the next generation of automated robots. Such improvement will be linked to Artificial Intelligence development based on deep learning. A.I. will then not only assists surgeon in the therapy definition, but also control and assist him intraoperatively as well as a pilot during a flight.

This new minimally invasive Image guided surgery is called Hybrid Surgery because it combines several technologies for a same objective and will be developed thanks to the development of Hybrid OP-Rooms such as the new OP-rooms installed at the Strasbourg IHU in 2016.



Pierre Mozer, ISIR, Paris, France

- **Title**: Robotics and Computer Aided Surgery in Urology : From Labs to Operating Rooms.
- **Abstract**: Urology is the medical and surgical specialty that focuses on the urinary tracts (kidneys, uretere, bladder) of males and females, and on the reproductive system of males (prostate and testicle). Urology is probably the most advanced surgical field of « soft tissue » for computer aided surgery and robotics.
  In this presentation after a historical introduction, we will focuse mainly on prostate and kidney applications from a clinical point of view with a technical perspective. We will introduce the advantages and drawbacks of Direct Image Guided Interventions versus navigation systems and teleoperative system as for example the Da Vinvi system (Intuitive Inc). To conclude, we will describe our experience of the process from « bench to bedside » to develop devices CE marked and FDA approved.

Jacques HUBERT CHU-INSERM, Nancy, France

Title: « Surgeon, bed-side surgeon and team training in robotic surgery »

Abstract: Unlike the name of the world's leading robotics company ("Intuitive") suggests, the efficient and secure use of a robot requires an incompressible learning time as for any new sophisticated tool. This learning involves two steps for the surgeon:

- Technical mastery of the instrument, essential whatever the level of the surgeon who wishes to start robotics. This initial **technical training** requires several days to automatically master all the robot's controls.

- Knowledge of the different steps of each surgical procedure. This **procedural training** is faster in experienced surgeons who are familiar with the surgeries they have already performed in open or laparoscopic approaches.

As is shown in the robotic literature, the learning curve has been done on the patient during years; few centers had the same approach as Nancy in 2000, when pioneer surgeons had worked for 1 year on inanimate model, then on pig model before starting on human beings. These on the patient learning practices are no longer eligible. This was the subject of clear recommendations from the French HAS (High Authority for Health): "never the first time on a patient".

Development of surgical simulators in 2008 (an already standard training technique in aeronautics and other fields) has transformed robotic pedagogy, as several companies (Mimic, Simbionix ...) are developing these instruments.

These simulators have become essential in the initial technical training programs, and allow to accelerate the mastery of the machine. Procedural training, which is more surgery oriented, still needs to be structured and to take benefit from more appropriate simulation techniques. With experience it became apparent that the surgeon's assistant has a much more important role in robotics than in any other type of surgeries and that a specific **team training** was mandatory. Here again an answer is brought by simulation with the development of specific simulators such as the Mimic XTT.

If surgical robots have achieved a degree of maturity, the surgeons’ training still requires to be better structured. Simulators have important progress to make in order to offer exercises whose quality is equivalent to what exists for video games.

Gastone Ciuti

The BioRobotics Institute, Sant'Anna School of Advanced Studies, Pisa, Italy

Title: Frontiers of Endoluminal Robotics: Current Achievements and Future Trends

Abstract: While surgical robotics becomes a well-established clinical practice, the need for better instruments (less invasive, less bulky, more functional and cheaper), arises. This motivates a quest for miniaturization and for dexterity in a new generation of low access trauma and no visible scarless surgical instruments and robots usable in endoscopic diagnosis and in novel surgical procedures such as N.O.T.E.S. and single-port laparoscopy. In this lecture, the development of endoluminal robotic instruments will be illustrated, with reference to actuated worm-like devices for painless colonoscopy, to wireless and wired robotic capsules for interventional endoscopy in the gastrointestinal tract, and to the frontier of millimetric-size capsules for peripheral blood vessels.

Paolo Fiorini University of Verona, Italy

- **Title:** Autonomous robots: motivations, challenges and impact of an emerging technology
- **Abstract**: Autonomous robots are under active research and scrutiny, because they capture the interest and imagination of large communities and have great potential impact on lifestyles, occupation and societal organization. Since the road to autonomy is long and difficult, it is likely that specific sectors, mostly professional, will lead the way by gradually introducing semi-autonomous features into existing robotic products. As it happened in the past, robotic surgery is a candidate to lead this process because it addresses a very small market segment, its users are experienced and sophisticated professionals, and there is a demand of novel features in surgical robotic products. In this talk I will discuss some of the motivations for the introduction of autonomous robots in surgery and in other fields, and the many technical challenges that need to be overcome. Since ethical and social aspects of robotic autonomy will determine the acceptance of this new technology, I will also report on the on-going discussion among the stakeholders about introducing autonomous robots into the job market.