UNIVERSITÉ DE STRASBOURG

Medical Robotics 2014-2015

Gestes Médicaux et Chirurgicaux Assistés par Ordinateur (GMCAO)

Course instructor:

Michel de Mathelin

Teaching staff:

Florent Nageotte, Stéphane Nicolau,
Hyewon Seo

UNIVERSITÉ DE STRASBOURG

Course description

- Chapter I: Definitions and state-of-the-art
- Chapter II: Registration
- Chapter III: Visual servoing
- Chapter IV: Virtual reality
- Chapter IV: Augmented reality

UNIVERSITÉ DE STRASBOURG

Bibliography

- IARP Workshop on Medical Robotics, Hidden Valley, may 2004: http://www.nsf.gov/eng/roboticsorg/IARPMedicalRoboticsWorkshopReport.htm
- CARS Workshop on Medical Robotics, Berlin, june 2005
- 6th European summer school in surgical robotics, Montpellier, september 2013: http://www.lirmm.fr/manifs/UEE/accueil.htm
- IEEE Transactions on Robotics & Automation, special issue on medical robotics, vol 19(5), octobre 2003.
- Proceedings of the IEEE, special issue on medical robotics, vol 94(9) september 2006.
- International Journal of Robotics Research, special issue on Biorob 2006, vol 26(11-12), 2007.
- IEEE Transactions on Biomedical Engineering, special issue on medical robotics, 2008.
- IEEE Engineering in Medecine and Biology Magazine, special issue on MRI Robotics, vol 27(3), 2008
- IEEE Robotics and Automation Magazine, Surgical and Interventional Robotics Tutorial, Vol 15, (2), pp 122-130, (3), pp. 94-102, (4), pp. 84-93.
- International Journal of Robotics Research, special issue on Medical Robotics, vol 28, (9) and (10), 2009.
- Medical Robotics – Ed. J. Troccaz, Springer 2012.

- International Conferences: ICRA, IROS, MICCAI, BIOROB, CARS, EMBC

I.1 Definitions (1)

Medical Robotics:

I. Surgical and medical assistance systems:

Robotics to assist doctors and surgeons – This course

II. Assistive technologies and rehabilitation robotics:

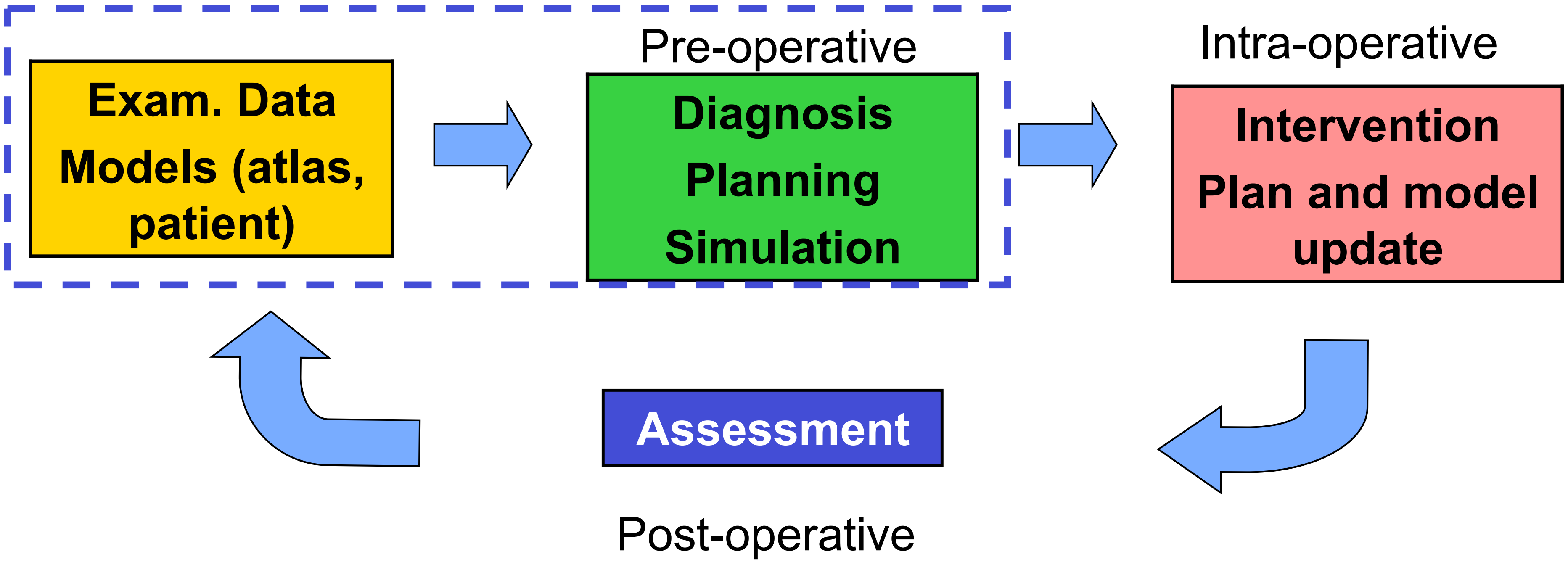
Robotics to assist people (elderly, disabled, injured, …)

- Prothetic devices, artificial limbs, orthotic devices, …
- Active implants, functional electro-stimulation, …
- Robotic moving and manipulation aids, smart living spaces, …
- Rehabilitation robotics for therapy and training

I.1 Definitions (2)

- **Surgical and medical assistance systems - Computer Aided Surgery (CAS) (GMCAO):**

  Computer and robotic asssistance to the planning and execution of medical acts using pre-operative and intra-operative imaging and signal monitoring

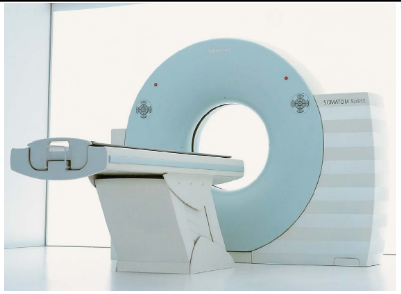


UNIVERSITÉ DE STRASBOURG

I.1 Definitions (3)

Complete CAS system :

Pre-operative and intra-operative Information

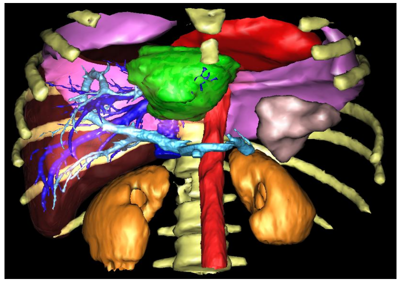


Videoscopy, endoscopy, CT, MRI, echography, PET, …

Monitoring,

Optical and magnetic 3D localization, …

Pre-operative and intra-operative information processing



Medical image processing,

3D visualization,

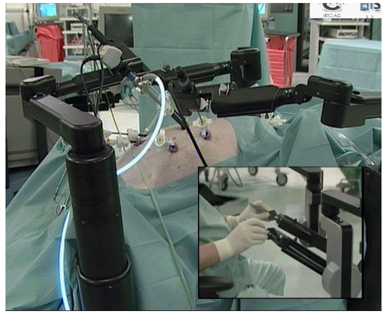
Planification,

Patient specific Simulation,

Registration,

Biomechanical and geometric models, atlas, …

Intra-operative intervention



Augmented reality, navigation

Surgical and medical robots,

Co-bots, …

Patient

Animal model

UNIVERSITÉ DE STRASBOURG

I.1 Definitions (4)

- **Possible classification of medical robotic systems:**

1. Actuation of the mobilities :

- Passive
- Semi-active
- Active

2. Medical applications :

- Orthopedics
- Minimally invasive surgery (MIS)
- Neurosurgery
- Interventional radiology
- Radiotherapy
- Odontology and maxillo-facial surgery
- …

I.1 Definitions (5)

3. Robotic tasks: This course

- **Registration:** localization of the instrument with respect to the patient with reference to the pre-operative planning and intra-operative imaging.
- **Positioning** : 3D positioning of instruments with respect to the patient
- **Trajectory tracking**: tracking with the instrument of a planned trajectory with respect to the patient
- **Comanipulation** : manual manipulation an instrument constraint in position, velocity or force, by a robotic device
- **Telemanipulation** : telemanipulation from a distance of an un instrument
- **Exploration**: exploration of a partially unknown environment
- **Simulation:** execution of the previous tasks in a virtual environment

I.2 State of the art (1)

- **End of the eighties:**
  - First generation of robots

    Transformed industrial robots
- **Nineties :**
  - Second generation of robots :

    Robots especially designed to improved surgical gestures
- **Today :**
  - Third generation of robots :

    Robots especially designed to performed surgical or medical acts impossible otherwise

UNIVERSITÉ DE STRASBOURG

I.2 State of the art (2)

A. End of the eighties:

- **First generation medical robot :**
  - Transformed industrial robots
  - Development of navigation application

- **Advantages of industrial robots:**
  - Accuracy : positionning of the instruments < mm
  - Repeatability : high repeatability of a specific task
  - Planification : execution of planned trajectories and tasks
  - Strength : gravity compensation of heavy loads
  - Hostile environment

- **Main medical applications:**
  - Orthopedics
  - Neurosurgery
  - Radiology and radiotherapy

UNIVERSITÉ DE STRASBOURG

I.2 State of the art (3)

- **Orthopedics**
  - The robot is used to precisely cut, slice, drill bones for implants (knee, hip, …)

  - **Commercial products:**
- **ROBODOC (ISS):**
  - Development with IBM (1986)

  Transformation of an industrial robot of the electronic industry

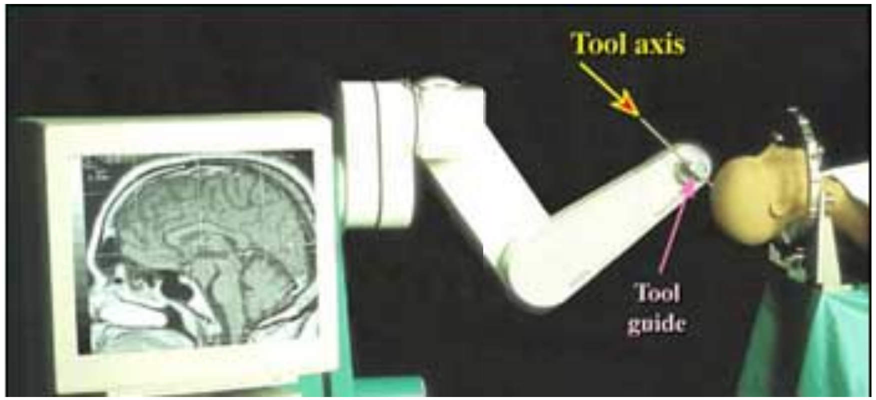
- **CASPAR (Maquet):**
  - Transformation of a Staübli robot

I.2 State of the art (4)

- **Neurosurgery:**
  - The robot is used to precisely position a probe, a needle or a lens with respect to the brain

Commercial products :

- **Neuromate (ISS):**
  - Developement in Grenoble in 1985



I.2 State of the art (5)

- **PathFinder (Prosurgics, UK):**

- **Surgiscope (Elektra, ISIS, France):**

  Delta robot

I.2 State of the art (6)

- **Radiotherapy and radiology :**
  - The robot is used to move around the patient a X-ray or a beam producing machine
  - The patient is on a robotized bed moved in front of the beam

- **Commercial products :**

  Cyberknife (Acurray)
  - Radiotherapy (Gamma rays)

I.2 State of the art (7)

- **Radiology:**
  Artis Zeego (Siemens)

- **Protontherapy :**

PPS (Patient Positioning System)

UNIVERSITÉ DE STRASBOURG

I.2 State of the art (8)

- **Avantages:**
  - More precise positioning of the instruments (assuming that an accurate registration is performed)
  - More accurate trajectory tracking
  - Tremor filtering
  - Weight compensation
- **Disadvantages:**
  - Robot-patient registration is needed
  - Increased duration of the procedure
  - Larger and trained medical staff
  - Cost
  - Room
  - Safety issues

I.2 State of the art (9)

B. Nineties:

- **Second generation medical robots**

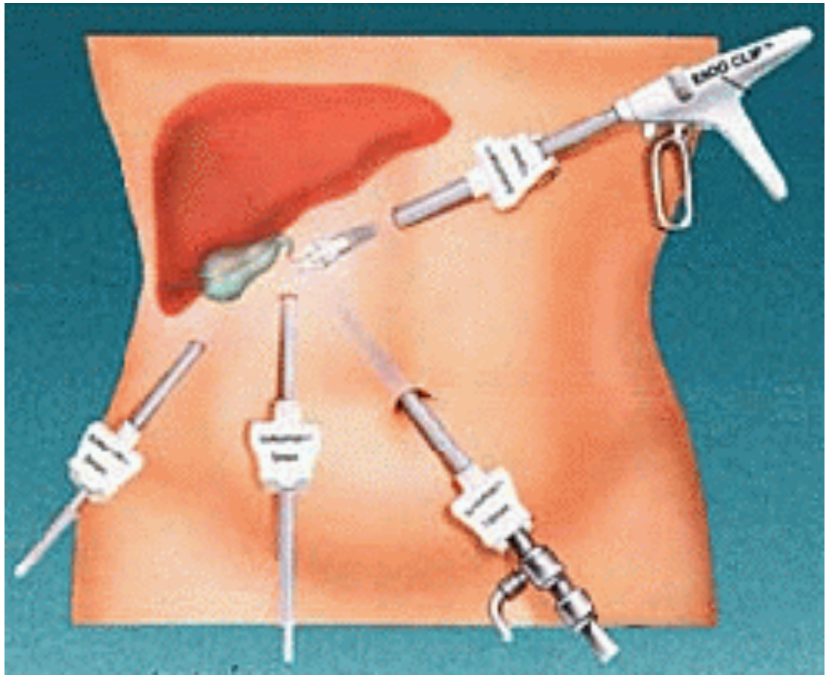
  Robots especially designed to improved surgical gestures

- **Robots dedicated architectures to manipulate the instrument**
  - Better accuracy
  - Increased dexterity (more degrees of freedom)
  - Comanipulation (constrain of motions, gravity compensation, tremor filtering)
  - Teleoperation (long distance surgery, hostile environment, motion scaling)
- **Main medical applications:** othopedics, neurosurgery, radiology +
  - Minimally invasive surgery
  - Echography
  - Others

UNIVERSITÉ DE STRASBOURG

I.2 State of the art (10)

- **Minimally invasive surgery:**
  - Surgical intervention through multiple insertion points
  - Endoscopic vision system
- **Indications**
  - Digestive surgery
  - Gynecology
  - Urology
  - Cardiac surgery
  - …



UNIVERSITÉ DE STRASBOURG

I.2 State of the art (11)

- **Avantages:**
  - Faster post-operative recovering
  - Lesser risk of infections
  - Reduced hospital stay and cost

- **Disadvantages:**
  - Tiring gesture for the surgeon
  - Indirect vision without depth information (mono-vision)
  - 4 DOF and inverted motions
  - Lack of force sensing

I.2 State of the art (12)

- **Robotized MIS:**

  Endoscope holders:

AESOP (Computer Motion)

Endo-Assist (Armstrong-Healthcare)

Voice controlled

Head motion controlled

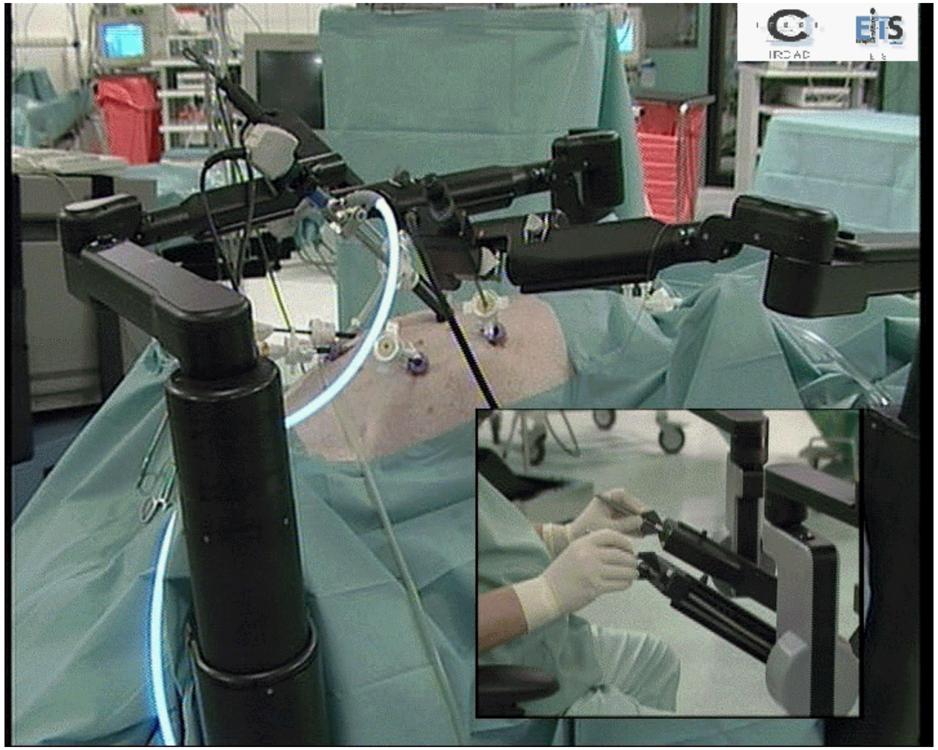
"The surgeon's third hand"

UNIVERSITÉ DE STRASBOURG

I.2 State of the art (13)

- **Teleoperated instruments holders**

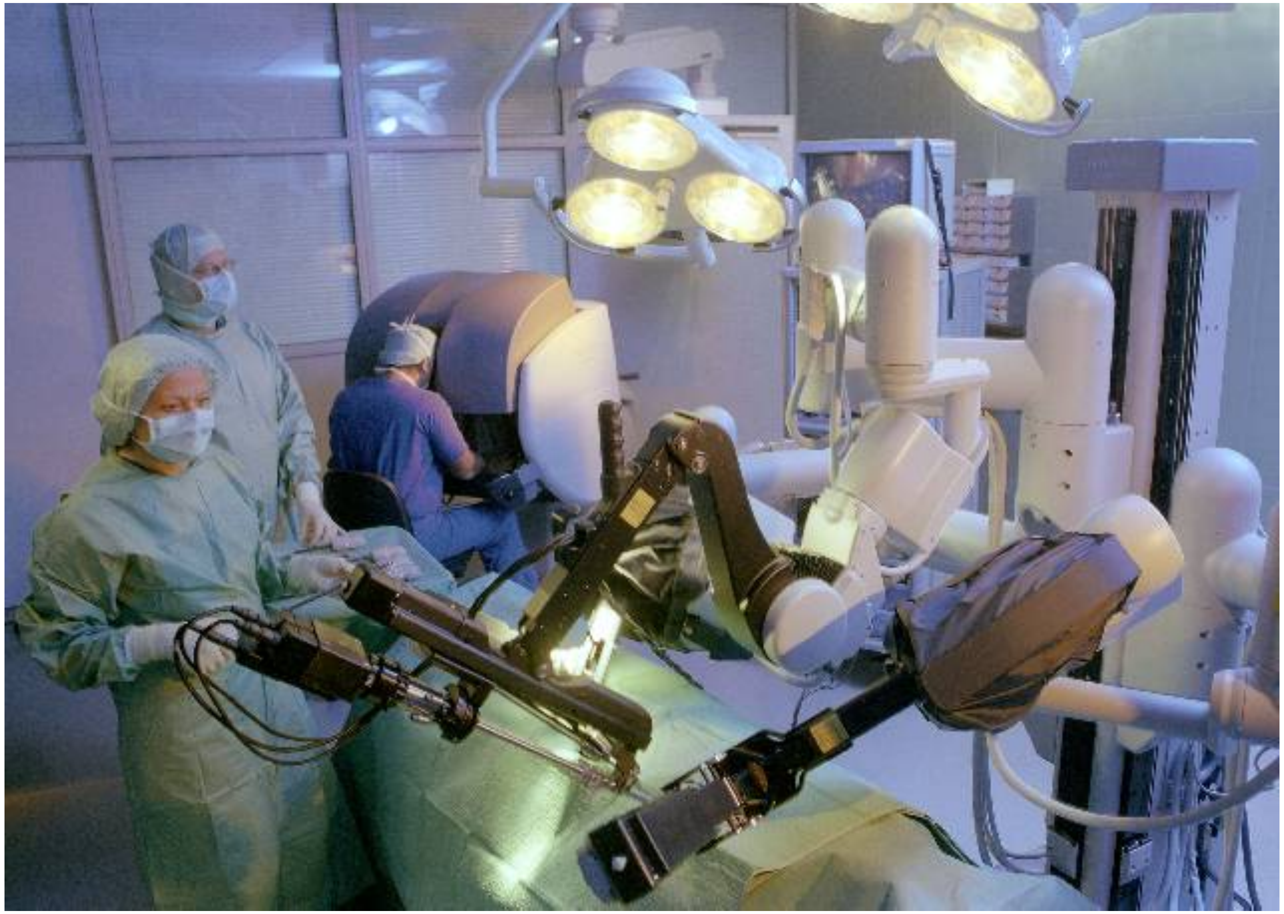
ZEUS (Computer Motion)



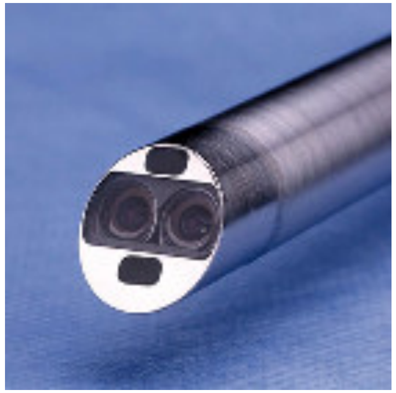
5 DOF instruments

I.2 State of the art (14)

DaVinci (Intuitive Surgical)



stereovision



6 DOF instruments

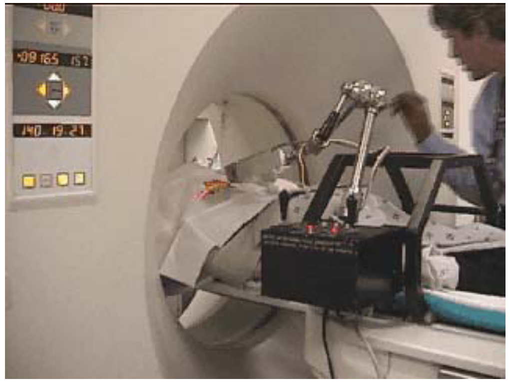
I.2 State of the art (15)

- **Robotized MIS:**

- **Advantages:**
  - Confort of the surgeon
  - Increased accuracy (tremor filtering, motion scaling)
  - Increased dexterity (5 or 6 DOF instead of 4)
  - One person less during the procedure
  - Long distance surgery made possible (Linbergh operation performed by Pr. Marescaux in september 2001)
- **Disadvantages:**
  - The instrument needs to be in the line of sight
  - No sensing of the contact with the organs
  - Increased duration of the surgical procedure
  - High cost (buying and maintenance)

I.2 State of the art (16)

- **Other applications:**
  - **Tele - echography:**
    - The Ultrasound robot, Hippocrate, …
  - **Radiologie interventionnelle:**
    - RCM-Paky-Acubot/JHU
  - **Orthopedics:**
    - Acrobot/(Imperial College et Acrobot Ltd)
  - **Neurosurgery:**
    - Neurobot/(Imperial College)
  - **Others:**
    - Dermarob, Probot /(Imperial College), Bloodbot/(Imperial College), …



Acubot

Acrobot

I.2 State of the art (17)

C. Today:

– **Third generation medical robots :**

Robots especially designed to performed surgical or medical acts impossible otherwise

- **Small light robots or miniaturized systems with dedicated architectures**
  – Patient mounted robots
  – Physiological motion compensation
  – Robotized instruments
  – Small cost

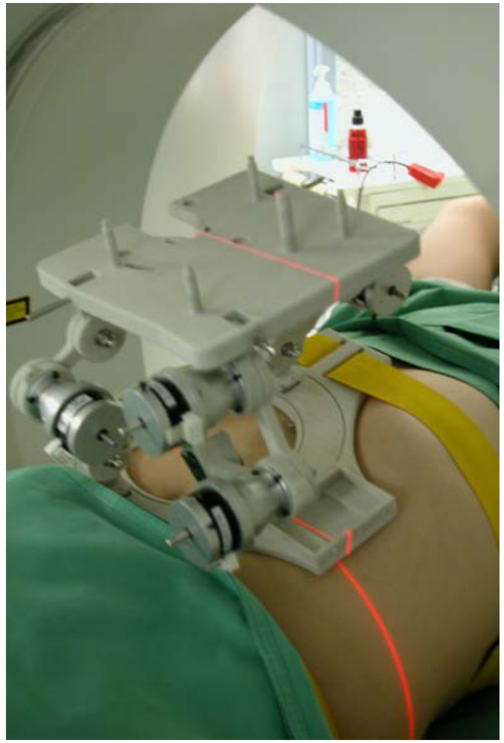
- **Main medical applications: no limitations**
  – New surgical procedures: NOTES, SinglePort, …

I.2 State of the art (18)

- **Patient mounted robots:**
  - **Orthopedics :**

Praxiteles, Grenoble

PIGalileo
(Plus Orthopedics
Switzerland)



  - **Interventional radiology:**

MARS, Technion 2002

CT-Bot, Strasbourg

I.2 State of the art (19)

– **Cardio-vascular :**

Sensei Robotics Cathether System
(Hansen Medical, USA)

I.3 Specific issues (1)

- **Safety**

The robot is expected to create no injuries to the patient or the medical staff:

- Redundant sensors
- Workspace, velocity, force constrains
- Safe mechanical design
- Software, electronic and mechanical fuses
- Manual procedure remains possible
- Automatic docking
- Small relative increase of the duration of the surgery
- Surgeon in the loop
- Others

I.3 Specific issues (2)

- **Operating Room constrains**

  The OP Room constrains should be taken into account:

  - Available space
  - Human-machine interface and ergonomy
  - Training of the medical staff
  - Interoperability with other equipements
  - Certification
  - Others

I.3 Specific issues (3)

- **Sterility**

  Le robotic device should be compatible with the sterility procedures:

  – The parts in contact with the patient should go into an autoclave or should be disposable or could go through a chemical cleansing

  – The other part in the sterile area should be wrapped in sterile bags in order to avoid contamination of the medical staff performing the surgical act

  – Others

I.4 Succesfull medical assistance (1)

Expected added-values of robots:

- Speed
- Accuracy
- Repeatability
- Automatic registration with pre-operative data
- Simulation
- Force, velocity and positioning constrains
- Augmented reality (visual, haptics, …)
- Gravity compensation
- Scaling of motions and forces
- Telemanipulation
- Automatic planned trajectory tracking
- Hostile environment
- Real-time integration of intra-operative data
- Added dexterity
- Tremor filtering
- Recording of intra-operative data

I.5 Succesfull medical assistance (2)

Technological success is different from medical or commercial success

Conditions for success:

- 3 specific issues are taken into account : safety, sterility and OP room constrains
- Several competitive advantages of robot over human are realized
- The doctor is in the loop
- A significative improvement for the patient (validated through clinical trials)
- An advantageous trade-off between cost and benefit for the patient