Classification of surgical robots

- different classification of surgical robots are available in literature
  - according to their role in Computer-Integrated Surgery (CIS) (Russel H. Taylor, 2003)
    - surgical CAD/CAM systems
    - surgical assistance systems
  - according to control paradigms (and the level of autonomy) (J. Troccaz, 2001)
    - passive systems
    - active systems
    - interactive (semi-autonomous) systems
    - teleoperated systems
  - according to the type of access (P. Dario, 2004)
    - traditional access
    - minimally invasive access
    - endocavitary/endoluminal access
  - according to the research areas and application
    - radiosurgery
    - orthopedic surgery
    - urologic surgery
    - neurosurgery
    - cardiac surgery
    - microsurgery
    - transplant surgery
    - ophthalmology
    - head and neck surgery
    - natural orifice transluminal endoscopic surgery (NOTES)
    - laparoscopic surgery
Role in Computer-Integrated Surgery (CIS)

- CIS systems are an example of an emerging paradigm of human-computer cooperation to accomplish delicate and difficult tasks.
surgery with a CIS system comprises three phases
Surgical CAD/CAM system

- transform preoperative images and other information into models of individual patients
- assist clinicians in developing an optimized interventional plan using a variety of appropriate means, such as robots and image overlay displays, to assist in the accurate execution of the planned interventions
- and Surgical Total Quality Management (STQM)
Surgical assistant systems

- work interactively with surgeons to extend human capabilities in carrying out a variety of surgical tasks. They have many of the same components as surgical CAD/CAM systems, but the emphasis is on intraoperative decision support and skill enhancement, rather than careful pre-planning and accurate execution.
The main technical elements of CIS systems

- Medical imaging
- Image processing, visualization, and modeling
- Preoperative analysis and planning
- Positional tracking and other sensing
- Robotics
- Human-machine interfaces
- Systems
- Training and simulators
Medical preoperative imaging

- Medical images, both preoperative and intraoperative, are the main source of information of CIS systems.

- Preoperative imaging devices are used to obtain images for diagnosis and surgical planning:
  - Film and digital X-rays (two-dimensional projections of spatial structures)
  - Computed Tomography (CT) (best suited for bony structures)
  - Magnetic Resonance (MRI) (best suited for soft tissue)
    - Can be used to visualize anatomical structures
    - Perform spatial measurements
    - Extract three-dimensional anatomical models
  - Nuclear Magnetic Tomography (NMT) (show functional anatomy, such as nerve activity, and are mostly used in the brain)

- The main drawback → static and don't always reflect the position and orientation of anatomical structures when surgery is performed.
Medical intraoperative imaging

- intraoperative imaging devices include
  - fluoroscopic X-ray (used in orthopedics to visualize and adjust the position of surgical instruments with respect to bones)
  - ultrasound images (used to obtain images of anatomy close to the skin)
    - used to support tumor biopsies, and colon explorations, among many others
    - they allow the surgeon to visualize in real time anatomy and surgical instruments inserted in a body
  - video image streams from endoscopes, laparoscopes, and surgical microscopes. They are mostly used for qualitative evaluation
- the main advantage of intraoperative images is that they provide an up-to-date image of the surgical situation
- however, the field of view and image quality are far inferior to preoperative images
- more recent intraoperative imaging devices include surgical Open MRI, surgical CT, and 3D ultrasound, which overcome some of the limitations of the more common imaging devices
Image processing, visualization, and modeling

- after image acquisition, the first task is visualization for diagnosis, evaluation, and planning
- image processing techniques for better evaluation
  - Co-registration
    - transforming different sets of data from different sensors, times, depths, or viewpoints into one coordinate system
    - to compare or integrate the data obtained from these different measurements (example obtain a 3D from PET – positron emission tomography and MRI)
- model construction algorithms are a prerequisite to preoperative planning, contour-based registration, anatomical atlas construction
- their input is a series of slices the output is one or more triangular meshes describing the geometry of the surfaces
once the diagnosis has been made and it has been decided surgery

the next step is to carry preoperative analysis and *elaborate a surgical plan of action*

- determining the access point of a biopsy needle
- complex gait simulations
- implant stress analysis
- radiation dosage planning

these systems can be viewed as medical CAD systems

in orthopaedics, planning systems are generally used to select implants and find their optimal placement with respect to anatomy
Positional tracking and other sensing

- determine in real time the location of selected anatomical structures, surgical instruments, and implants during surgery
  - electromagnetic tracking
  - optical tracking
  - acoustic tracking
  - tactile sensors
Robotics

• ...
Human-machine interfaces

- technologies → speech, computer vision and graphics, haptics...
- common interfaces → joysticks, touch screens, push-buttons, foot-switches...
**Systems**

- **information enhancement systems**
  - **navigation systems**
    - CT or MRI augmented with CAD models of tools and implants
    - Intraoperative images, such as fluoroscopic X-ray, ultrasound, or open MR images augmented with projections of tool CAD models and implant axes
    - Intraoperative video streams from an endoscopic camera or a surgical microscope, shown alongside or fused with preoperative CT or MRI image
  - **augmented reality navigation systems**
    - Drawback of the navigation systems described above is that they require the surgeon to constantly shift his attention from the patient to the computer display and back
    - Overcome this drawback by bringing the display right where the surgeon needs it
  - **virtual reality systems**
    - Diagnostic endoscopy and colonoscopy, replace an actual exploration on the patient with a virtual exploration on MRI images
    - Three-dimensional reconstruction of the anatomical structures of interest
    - Robotic systems for precise preoperative plan execution

- **robotic systems for precise preoperative plan execution**
  - To ensure not only precise positioning but also precise execution
    - ROBODOC developed for hip arthroplasty consists of a preoperative planning workstation (CT data) and a robotic arm with a milling to prepare the femoral canal
    - LARS robotic system for precise needle insertion under radiological guidance

- **robotic systems for human augmentation**
  - Da Vinci, Zeus, microsurgery robots

- **other robotic systems**
Training and simulators

- applications in surgical training and simulation
  - robots providing force feedback from computer models of instrument–tissue interaction (haptic interfaces, e.g. Phantom)
  - developed systems
    - arthroscopic knee surgery
    - tubal anastomosis
    - laparoscopic surgery
  - advantages
    - reduced training costs
    - trainees can review their data to analyze technique
    - trainers can evaluate progress and skill level
    - surgeons can explore new surgical techniques, and by incorporating preoperative image data, patient-specific procedures may be rehearsed
Control paradigms

- passive systems
  - manually guided probe
  - needle holder that compensate patient motion

- active systems
  - STAR, ROBODOC, Cyberknife
  - NeuroMate (minimally-invasive neurosurgery)
    - fiducials markers located in the patient’s head
    - ultrasound
Control paradigms

- interactive (semi-autonomous) systems
  - MURAB (image guided biopsy)
  - MRI-Ultrasound (US) registration

- teleoperated systems
  - Da Vinci, Rams, Microsure
Type of access

- traditional access
- minimally invasive access
- endocavitary/endoluminal access
Research areas

- radiosurgery
- orthopedic surgery
- urologic surgery
- neurosurgery
- cardiac surgery
- microsurgery
- transplant surgery
- ophthalmology
- head and neck surgery
- natural orifice transluminal endoscopic surgery (NOTES)
- laparoscopic surgery
From teleoperated to cooperative robots a number of prototypes have been created for research purposes or are under development:

- NeuroArm robot by University of Calgary
- RAMS (Robot-Assisted Micro-Surgery) System by NASA/JPL-Caltech
- Micro Surgical Robot (MSR) by MicroSure
- Smart Tissue Autonomous Robot (STAR) by Children’s National Health System
- Pico Robot by MMI Micro
Robot-assisted laparoscopic surgery

Laparoscopic surgery (Manual)
- Small Incision (up to – 1.5 cm)
- Reduce risk of bleeding and pain
- Significantly shorter hospital stay
- Less exposure of internal organs to external contaminants

Disadvantages:
- Limited range of motion at the surgical site resulting in a loss of dexterity.
- Poor depth perception.

Conventional open surgery
- Blood loss
- Post-operative pain
- Prolonged hospital stay
- Risk of infection

Advantage:
- Full visualization of target site
- Natural ergonomics
NOTES

Single port robot-assisted surgery

- Minimize trauma
- Reduce various complications associated with external incisions such as skin scars, postoperative pain and wound infections.