Humans–robots–humans:
who is operating who?

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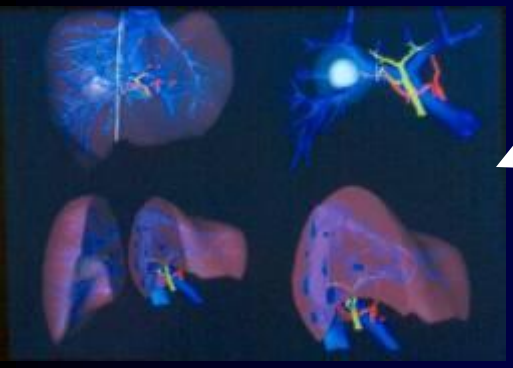
Shanghai Lectures ‘11
The global, virtual lecture hall 08.12.2011.

The Prejudices

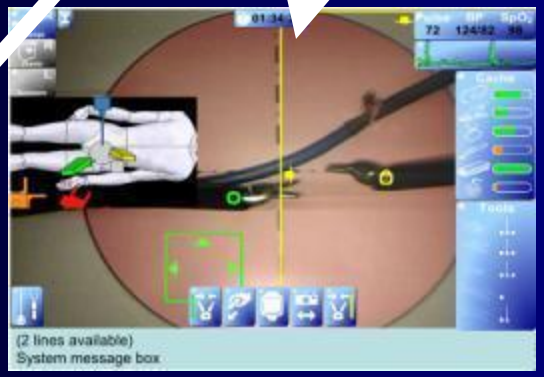
New paradigm

Telesurgery



Pre-op planning

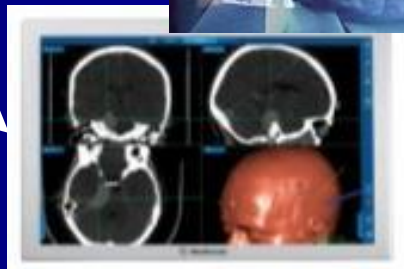
Simulation, practice and warm-up



Sensor fusion

MIS/open surgery

Augmented reality

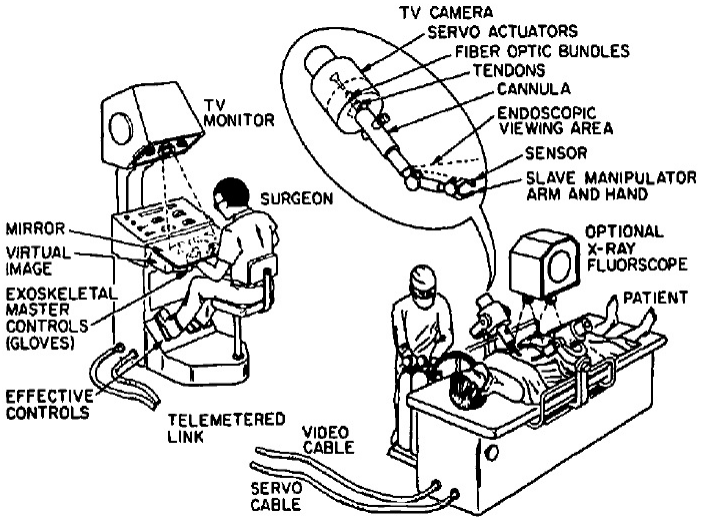


Intra-operative navigation

Robot-assisted surgery

Source: Joel Jensen, SRI International, Menlo Park, CA

The Beginning



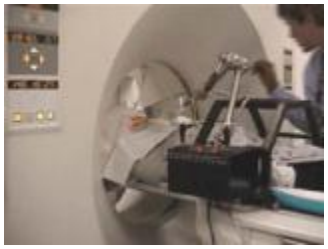

MR
CT
Transverse MR
CT
Tool axis
J5
J4
Tool guide

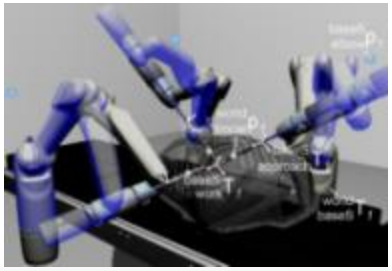
CIS Basics

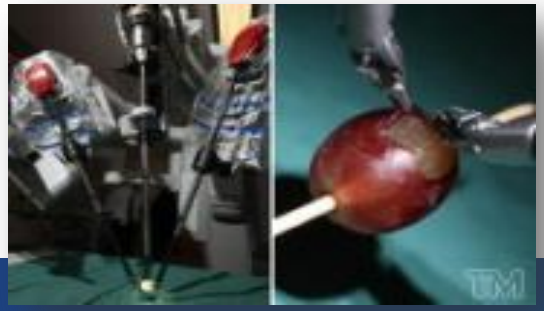
You name it!

- CIS: Computer-Integrated Surgery
- CIIM: Computer-Integrated Interventional Medicine
- CAS: Computer-Assisted Surgery
  Computer-Aided Surgery
- IGS(T): Image-Guided Surgery (Therapy)
- R-MIS: Robotic Minimally Invasive Surgery

- Surgical CAD/CAM:
  - CASD Computer Aided Surgical Design
  - CASM Computer Aided Surgical Manufacturing
- Surgical TQM: Total Quality Management

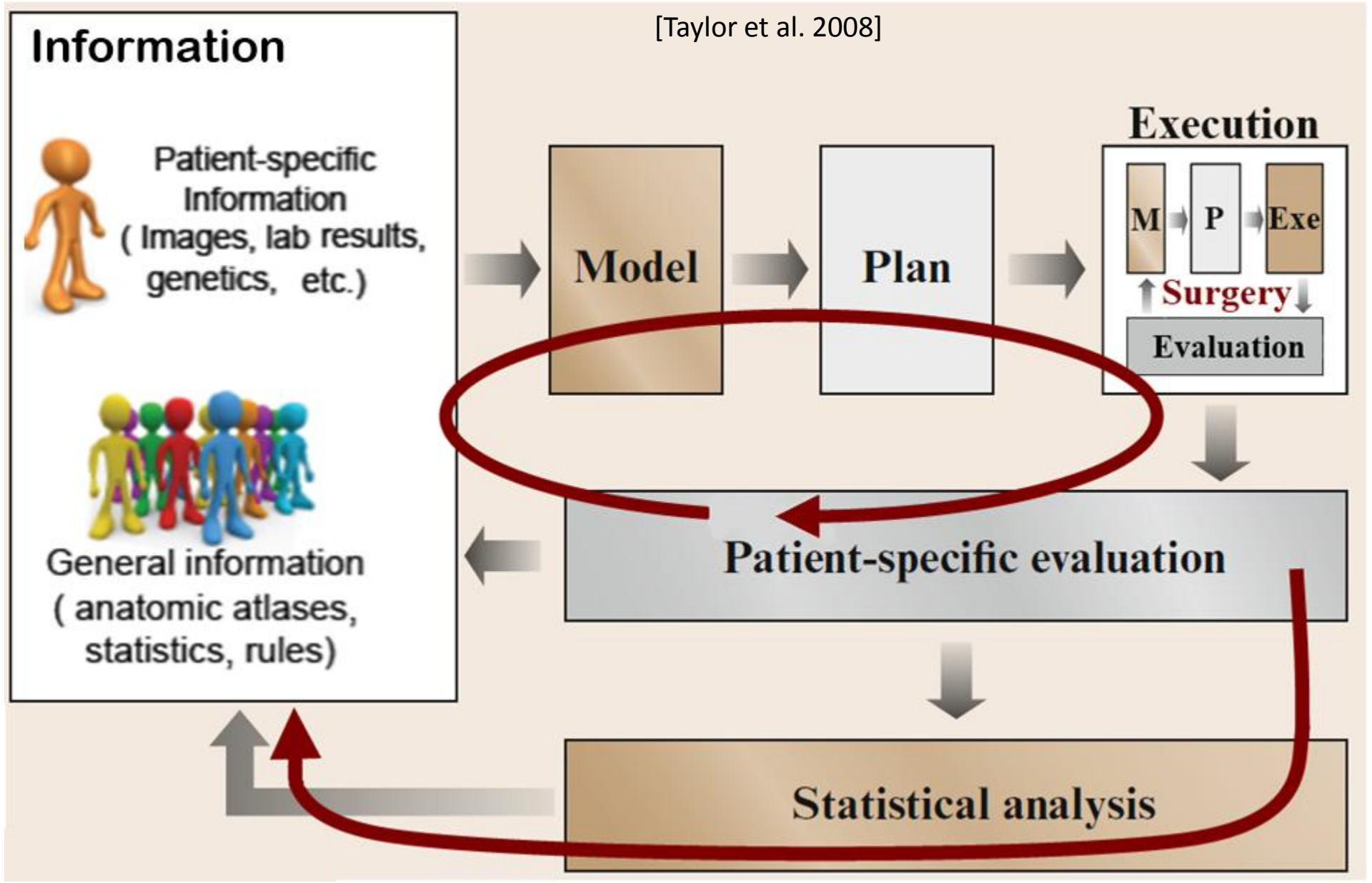






Computer-Integrated Surgery

[Taylor et al. 2008]



Market for Computer-Integrated Surgery

$20 B estimated market for **IGS** and medical imaging

$20 B estimated market for **MIS** by 2015

$5 B estimated for **robotic surgery**
Forecasted to grow $14 B by 2014

Credit: BrainLAB

Credit: Gy. Wéber

Credit: Renishaw

Source: *Frost & Sullivan, TMD, Piribo*

Robotic approaches in CIS

- **Human-in-the-loop control**
  - Leave the mapping to the surgeon

Credit: White House

- **Registration (image) based**
  - Human oversight

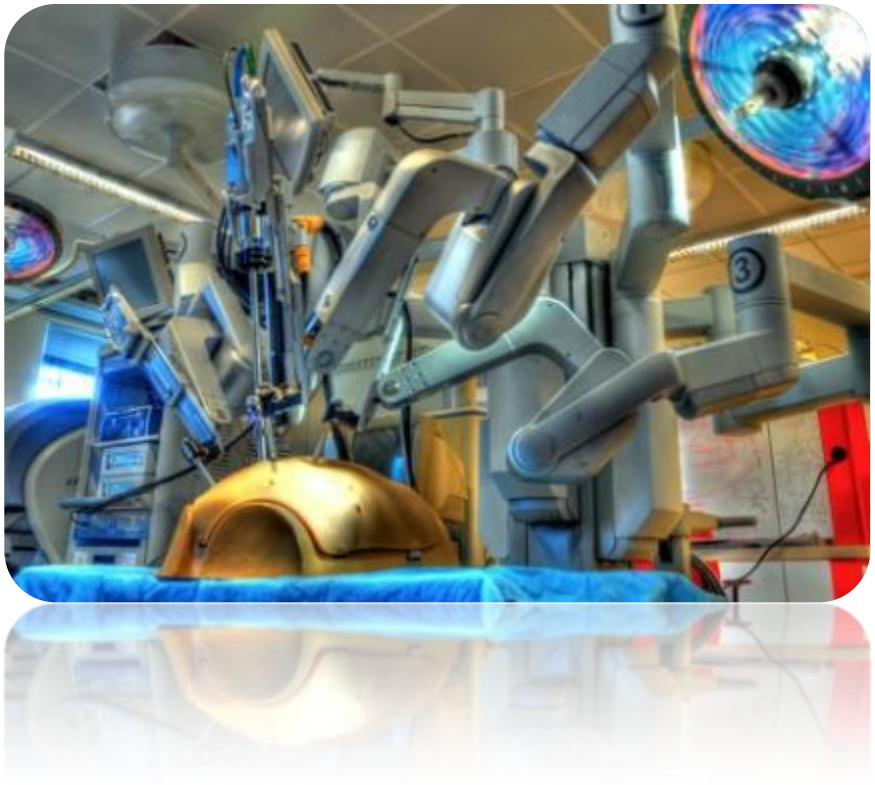
Credit: ISS Inc.

Surgical robotic numbers

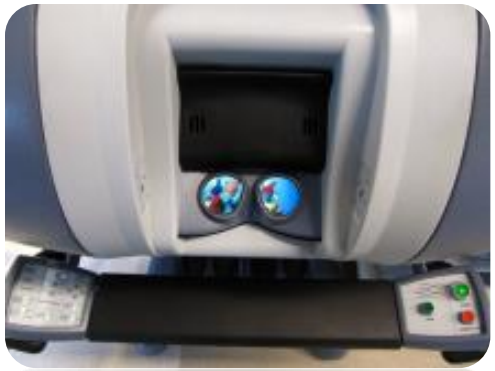
- NeuroMate: ~30 (~15 by ISS)
- ROBODOC: ~50 (~25 before 2000)
- Zeus: 50 (~2002, discontinued 2003)
- MAKO: 86 (~09 2011)
- SpineAssist: 3 (~07 2010 in the USA)
- Hansen Sensei: 120 (~03 2011)
- CyberKnife: 200 (~2010)
- da Vinci: ~2100 (~12 2011)

IG Teleop IG IG Teleop IG Teleop

Intuitive Surgical's da Vinci



Complete teleoperational system

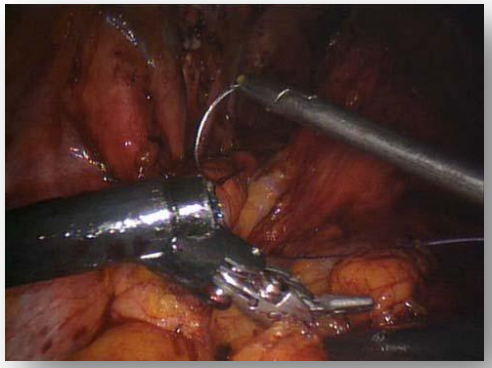


master ⟷ slave

Complications

Technical problems (requiring laparoscopy or conversion)

- [Murphy 2009]: device failure 0.2 – 2.6% (survey paper)
- [Borden 2007]: Hardware errors, e.g., wrist mechanical failure, or break



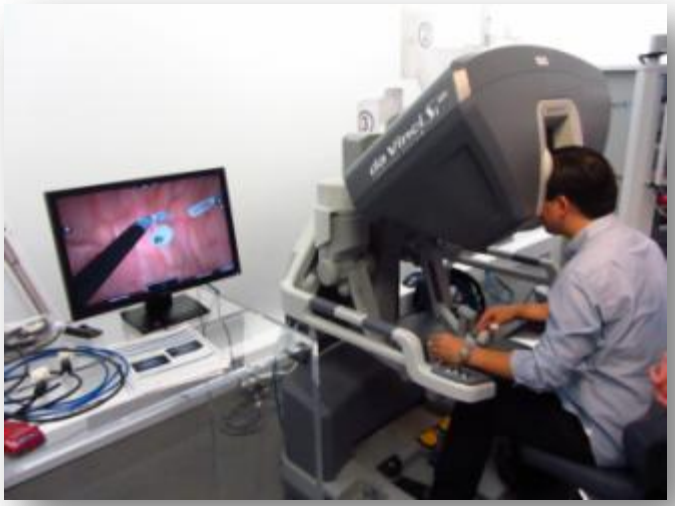
Accidents and malpractice

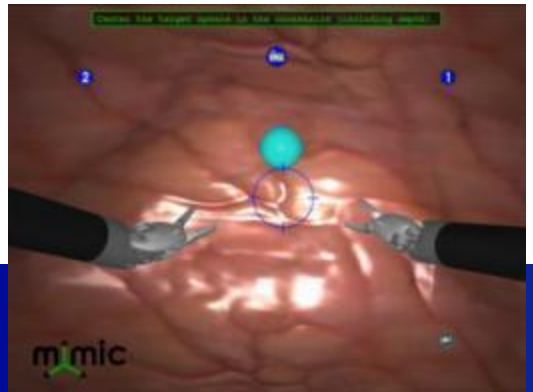
- 2002 Tampabay Hospital
- 2009 Boca Raton Hospital
  - 42-y patient died after prostatectomy
- 2010 collective lawsuit in the USA
  - Wentworth-Douglass Hospital
  - 4 surgical errors with robot
- Cleveland Clinic sued by retired colonel in 2010

Role of simulation

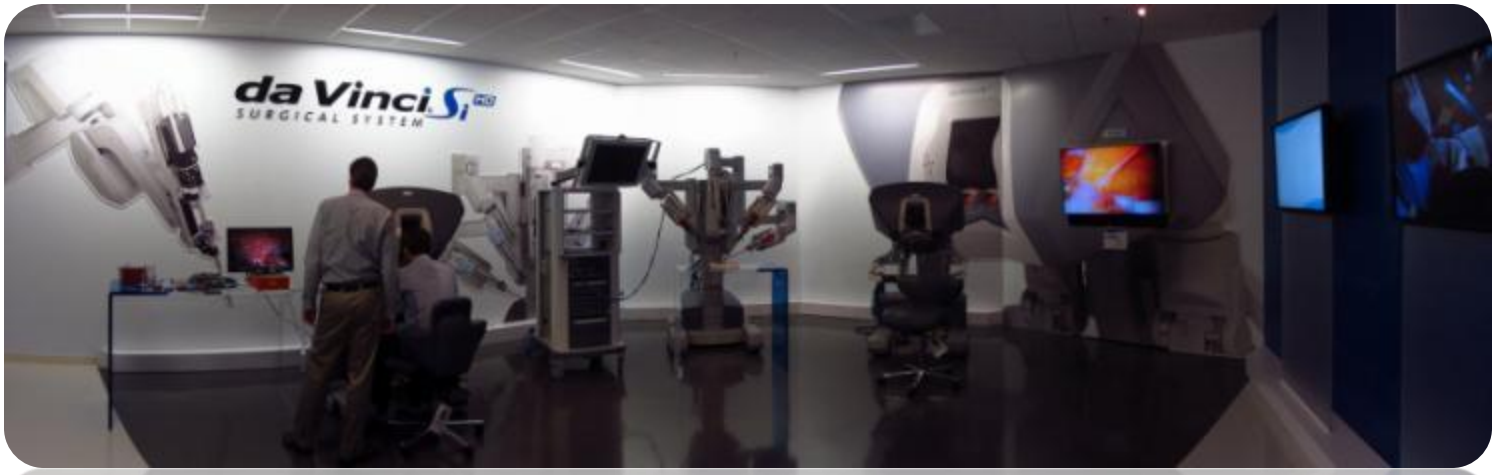
Learning curve

- Skill Simulator (MIMIC Inc.); ROSS
  - 1 week initial training, while 200 procedures are needed app.
  - “Language of surgery” project





Current trends in robotic surgery



Da Vinci competitors—M7

- **SRI International**, 1998–
- Light weight—15 kg
- 7 DOF arms
- 1:10 scale down
- tremor filtering

Raven

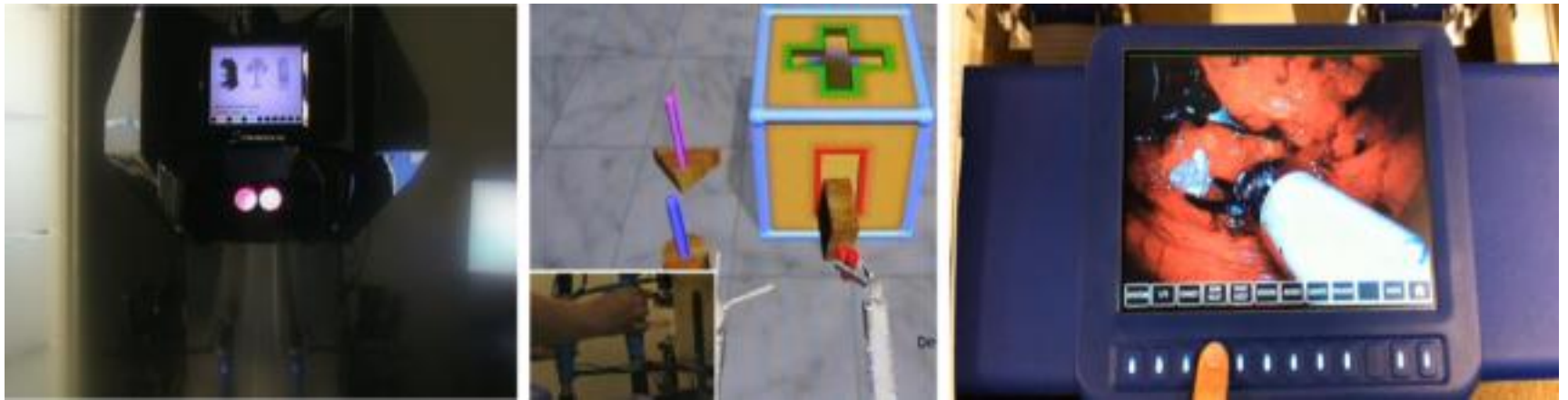
- **University of Washington**
- DARPA, OR of the Future
- 22 kg overall mass
- Field trials in 2007
- NASA trials in 2009
- 2nd generation: 8 devices

Credit: University of Washington

Amadeus Composer/Maestro

Titan Medical Inc. (CA)

- KUKA's 7 DOF lightweight arm
- FDA submission in late 2014
- PI: Dr. Rayman
- IPO + grants



Credit: Titan Medical Inc.

ALF-X

- Advanced Laparoscopy through Force-RefleCT(X)ion
- **Sofar S.a.P.** (Milan, IT)
- NES Academy, EU grant support
- 2006–

Credit: Sofar S.a.P.

Sofie

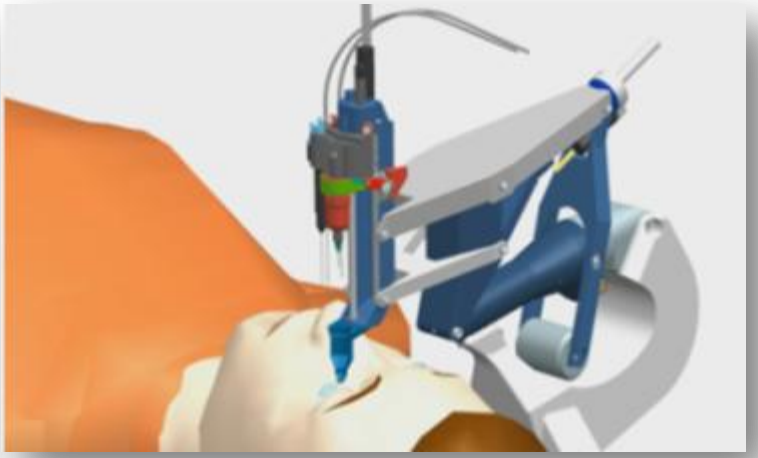
- Surgeons Operating Force-feedback Interface Eindhoven
  - **Tech. University of Eindhoven(NL)**

Credit: Tech. University of Eindhoven

Eye surgery robot

- **Tech. University of Eindhoven (NL)** and
  - K. U. Leuven
- Tremor filtering, 1:10 motion scaling
- Haptic feedback
- RCM mechanism
- Tools of a diameter of 0.5 millimeter (forceps, scissors and drains)
- Fast instrument changing

Credit: Tech. University of Eindhoven



The DLR robots

- **Deutsches Zentrum für Luft- und Raumfahrt**
- KineMedic (discont.)
- MIROsurge
  - 10 kg weight, 3 kg pl
  - 3 robot, 1 animal trial

Credit: DLR

China

Micro Hand A (妙手A)

Tianjin University and Nankai University

- Tested at the Tianjin Medical University General Hospital (June 2010–)
- And also Southern Medical University

Orthopedic robot

Xinqiao hospital in Chongqing

- 2010, first trial

Japan

University of Waseda

- Beating heart surgery robot
- MRI-compatible robot

Credit: U. Waseda

NAVIOT (Hitachi Co.)

- First commercialized robot in Japan
- 5-bar linkage mechanism for safety design to restrict moving area

Credit: Hitachi

Credit: U. Waseda & Hitachi

IGS development

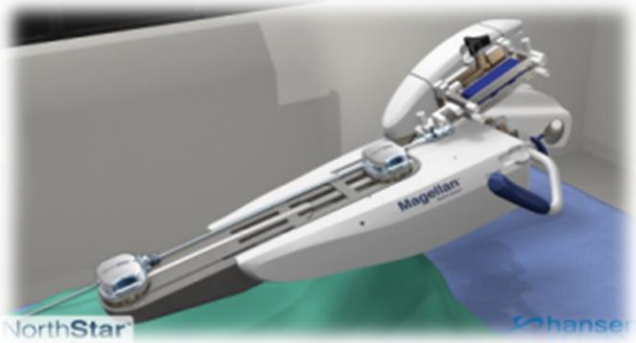
ROBODOC (Curexo Tech. Co.)

NeuroMate (Renishaw plc.)

MAKOplasty (MAKO)

Magellan (Hansen Medical)

ROSA (MedTech co.)



Credit: MAKO, Rosa, Curexo, Renishaw

neuroArm

IMRIS (2010–)

Developed by Univ. Calgary and MD Robotics

- With experience gained at the Space Station SPDM
- 1 systems, MR compatibly up to 3 T
- First brain tumor patient: 2008
- Few dozen human surgeries
- Looking for FDA clearance in 2012
    - Treating up to 120 patients

Univ. of Calgary,
www.neuroarm.org

Future of robotic surgery

Future trends

Bottom line: better clinical outcome

- Augmenting accuracy and/or efficacy
- Increasing the added-value
- Providing smarter tools

→

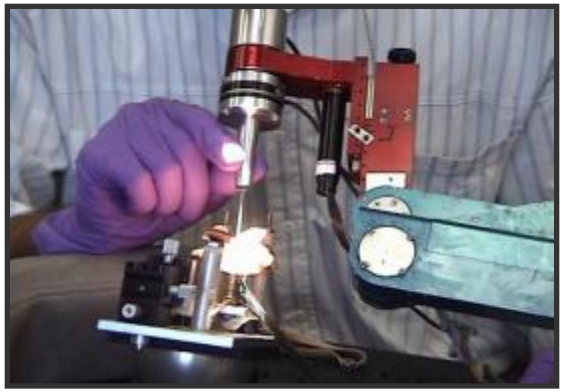
- Task specificity
  - e.g. prostate biopsy robots
- Reduced size
  - micro/nanorobot
- Increased safety
  - MR compatibility

Cooperative control

"Hands-on" technique

- The master and the slave devices are identical
- Real-time force/torque measurement
- Provides haptic feedback

Application examples



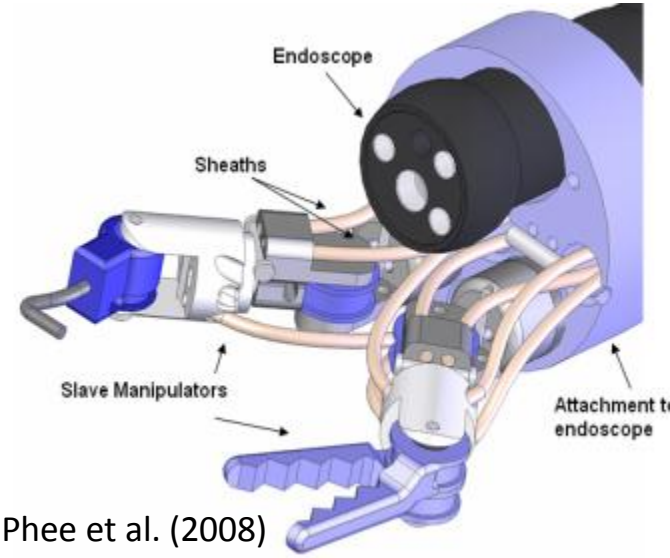
- **Acrobot** (Imperial College, London)
  - Total knee replacement [Jakopec 2003]
- **PathFinder** (Armstrong HealthCare, UK)
  - IG neurosurgery [Finlay 2006]
- **Steady-Hand Robot** (JHU, USA)
  - Sinus surgery [Li 2007]
  - Skull base surgery [Matinfar 2007]
  - Eye robot: retinal vein cannulation [Balicki 2009]
- **Neurosurgery (Skull Base) Robot** (JHU, USA)
  - Image-guided system with virtual fixtures
  - Improved safety and ergonomics [Haidegger 2008]

Single-port devices

Similar to NOTES (Natural Orifice Tr.)

- Nanyang Technological University, Singapore
- CardioArm (Carnagie Melon)
- Suturing machines

CardioArm - CMU



Phee et al. (2008)

Swallow-able devices

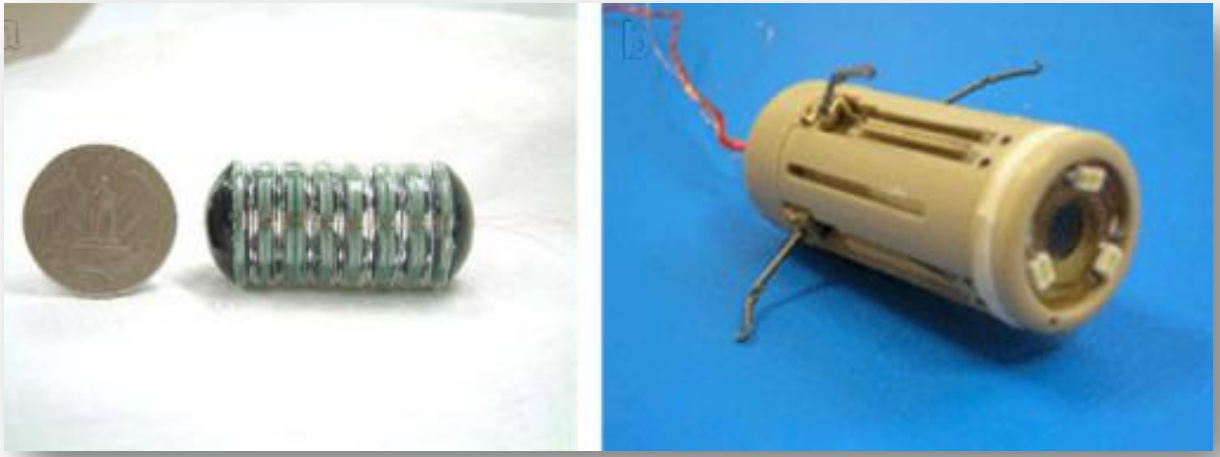
In the past: only for imaging

- PillCAM
- Phillips cam, …

Now: with actuators

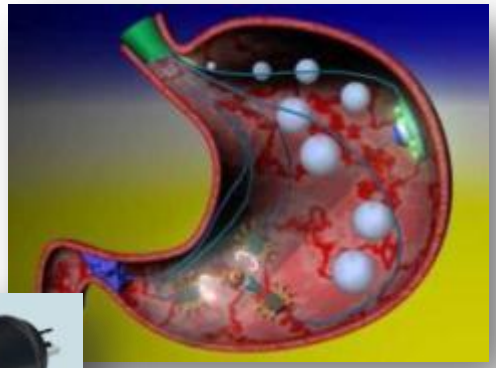
- Scuola Sup. St. Anna:
  - Capsule robot
  - VECTOR : Versatile Endoscopic capsule for Gastrointestinal tumour recognition and therapy

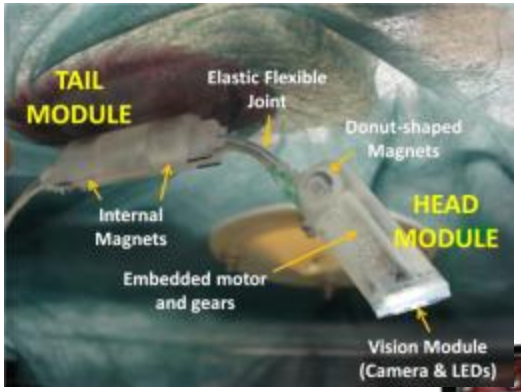
VECTOR

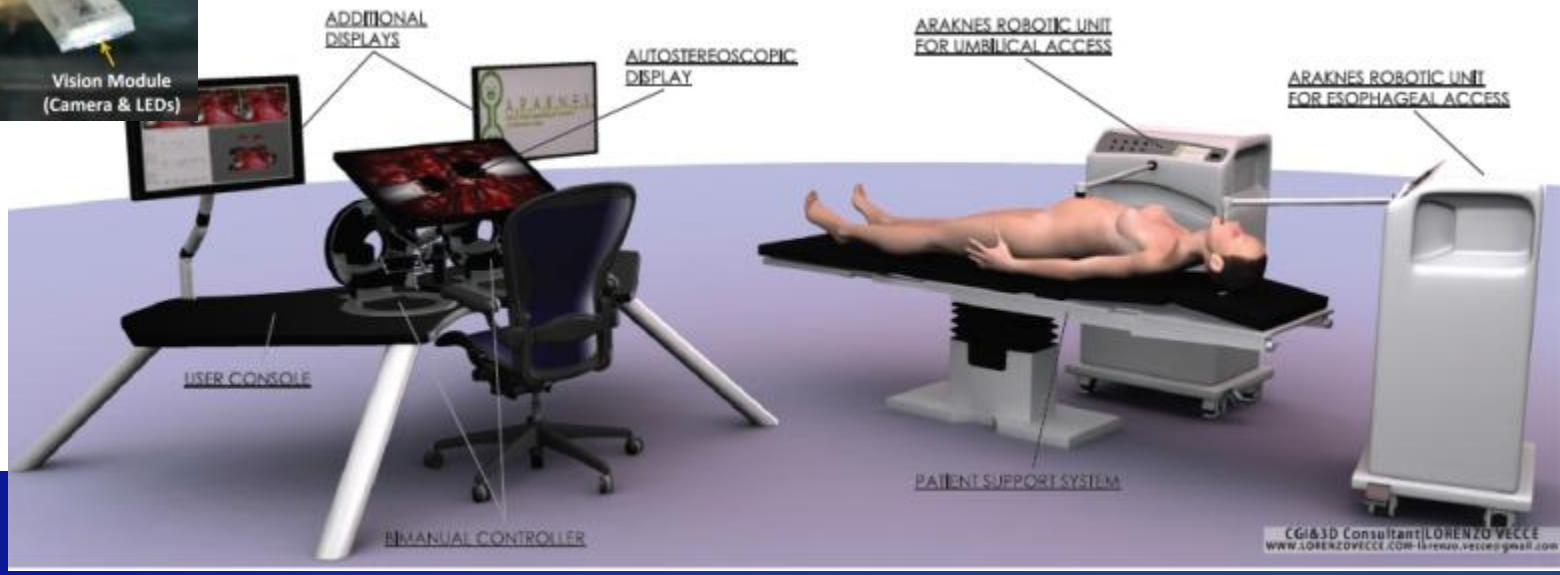


Tethered robots

- ARAKNES project
  - EU FP7 consortium
  - Scuola Superior Sant' Anna, Pisa (coordinator)
  - *www.araknes.org*



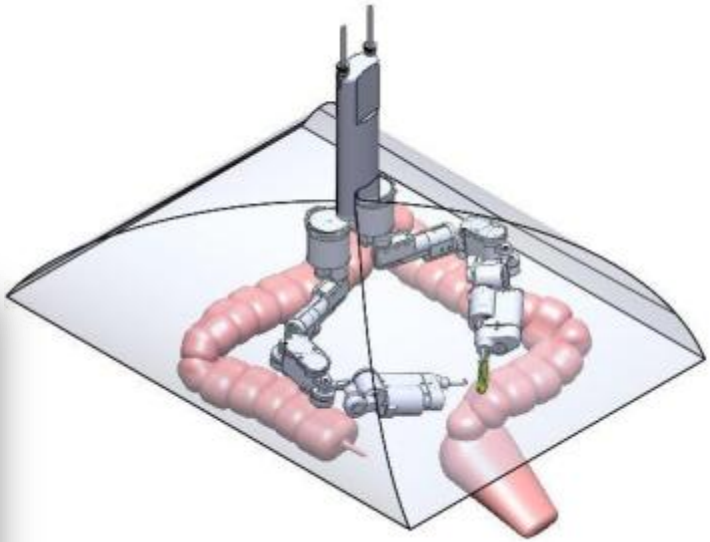


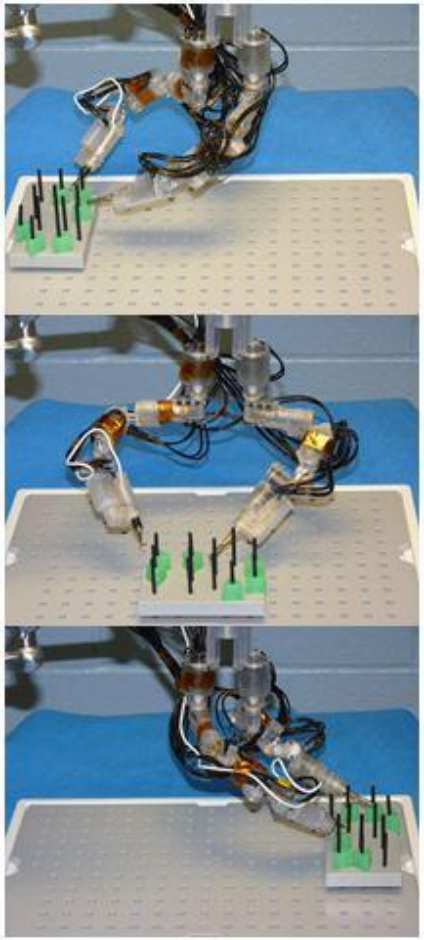


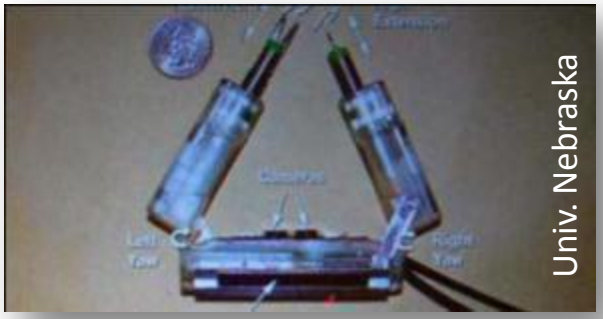
Small-scale MIS robotics

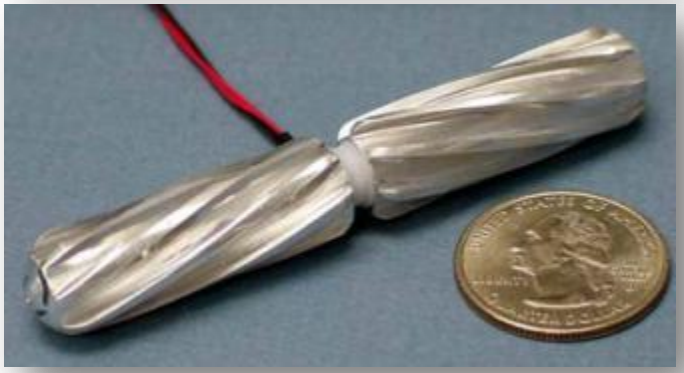
University of Nebraska

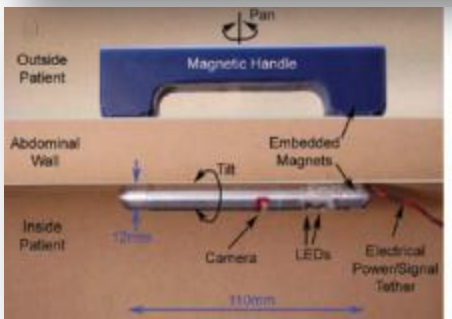
D. Oleynikov et al.







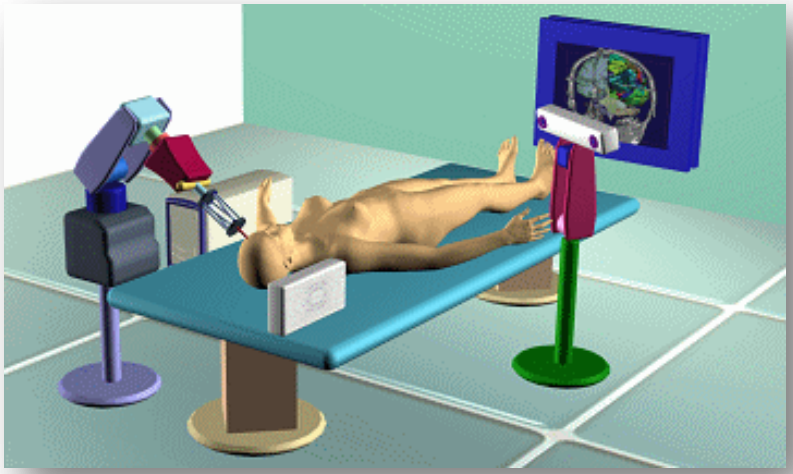




[McCormick, 2011]

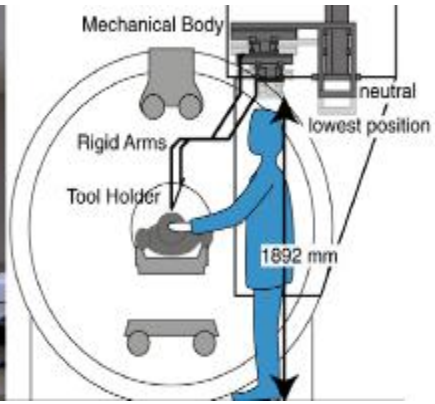
EU FP6–7 projects

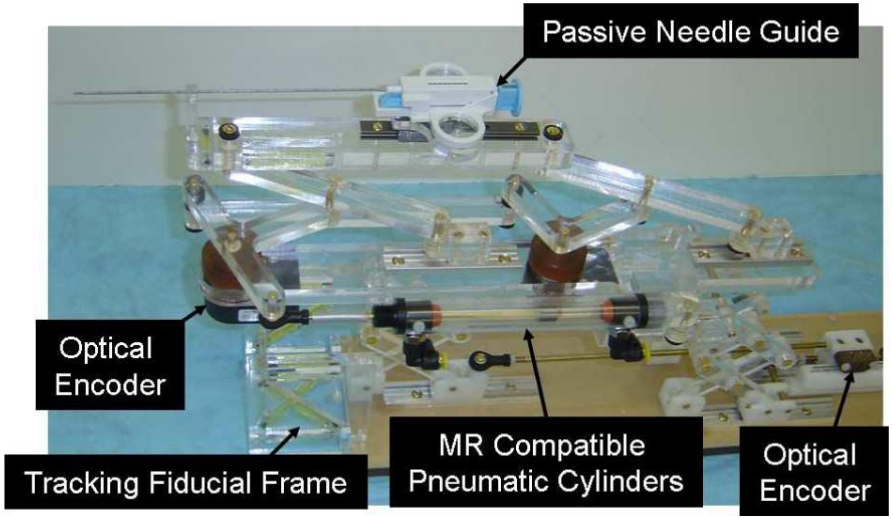
- ACTIVE
  - Awake epilepsy surgery with soft robots and motion compensation
  - *www.active-fp7.eu*
- ROBOCAST
  - Keyhole neurosurgery with micro-macro robot
  - *www.robocast.eu*

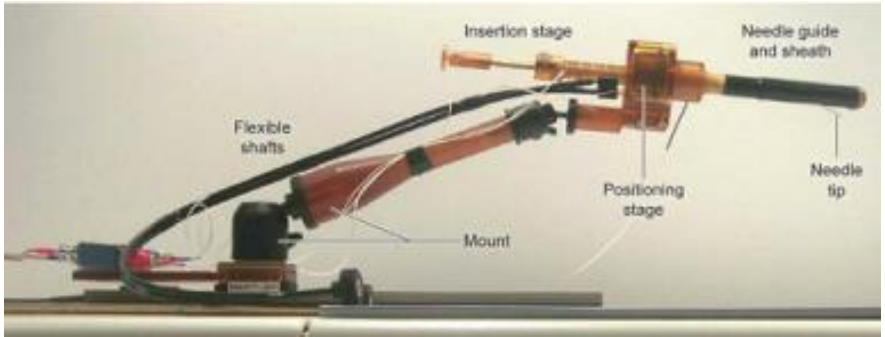


In-vivo imaging

- MR compability
  - JHU/Queens brachy robots
  - WPI AIM lab robots
  - Harvard/AIST open bore MR robot

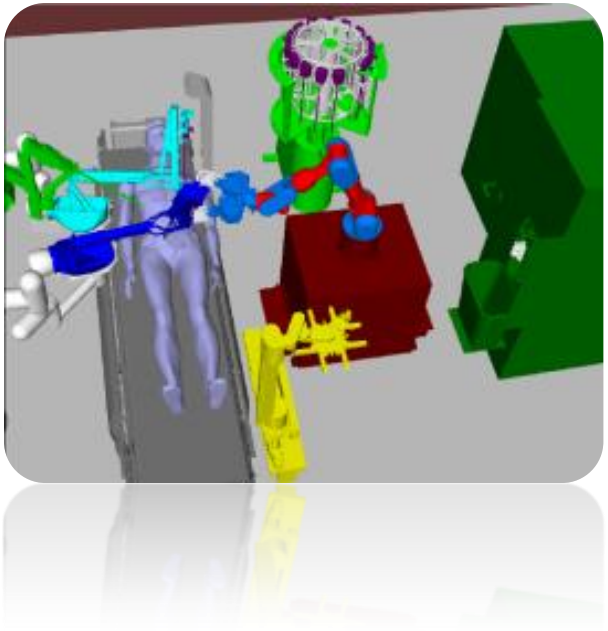






Credit: CISST ERC, Harvard Medical School, WPI

Telesurgery—far-far away



Telesurgical experiments

Long range procedures around the world

The Lindbergh operation

- 7th Sept, 2001
- New York <---> Strasbourg
- Hour-long gallbladder removal
- Master setup in France Telecom office
- Average latency: 150 ms

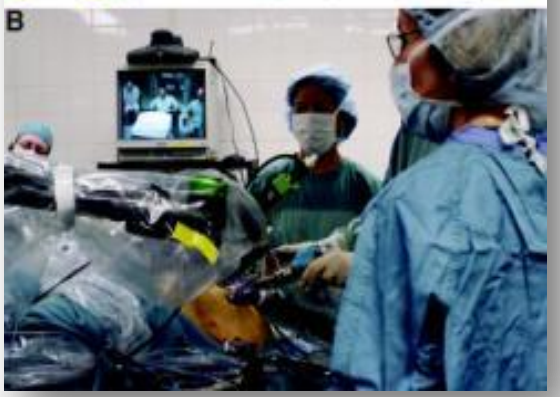
CMAS

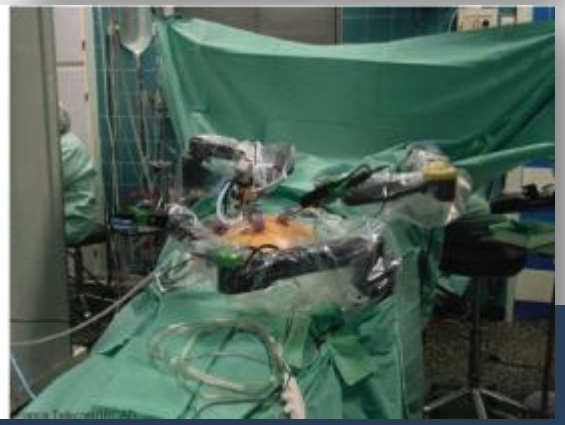
- 1st regular telemedicine network (in Canada)

PlugFest 2009

- Telesurgery experiment with 14 systems world wide

Many intercontinental trials



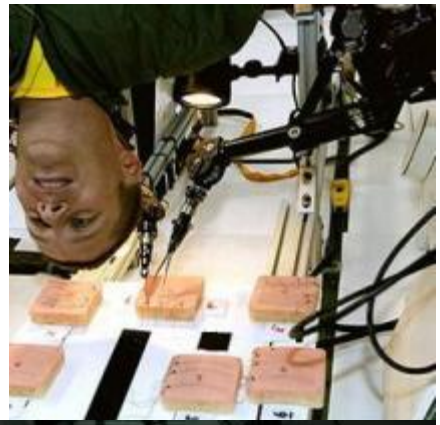


Surgery in space

On board & in simulated environments

NASA zero G experiments

- On board of a DC-9 hyperbolic aircraft
- Simulated surgery (2007)
- Suturing with M7 robot
- Human control / automated task execution



NASA NEEMO program

- 14 missions in an underwater habitat in Florida
- Robotic surgery mission objectives
  - Telesurgery with AESOP (2004)
  - Simulated procedures with the M7 (2006)
  - Telesurgery with Raven and M7 (2007)

Zero G surgeries

- First surgery in weightlessness on a rat (2003)
- Removal of a cyst from the arm of a human (2006)
- Parabolic flights: 20-25 s of microgravity
- ESA Zero-G plane (modified Airbus A-300)

Credit: ESA, NASA

Takeaway

- High R&D costs
  - da Vinci was created with $0.5B
- Long development time
  - From idea to product: 8-10 years
- Universality vs. added value
- Low selling numbers
- National differences in regulations
- Surgeons' compliance
- Looking for "cheap&easy" solutions

Takeaway II

“Get smarter people than you are, and make them excited about your problem!”

/R.H. Taylor/

”If you enjoy your job, you will never have to work for your entire life.”

/ Teik Seng Tan/

Takeaway III

Innovation in MIS free course (not only for students):

www.ircad.fr/student

IEEE RAS: **http://wiki.ieee-ras.org/mab/sac**

Thank you for your attention!

Post script

This presentation is available at

http://tinyurl.com/ShanghaiL-Haidegger

SurgRob

a blog on CIS and medical robotics

http://surgrob.blogspot.com