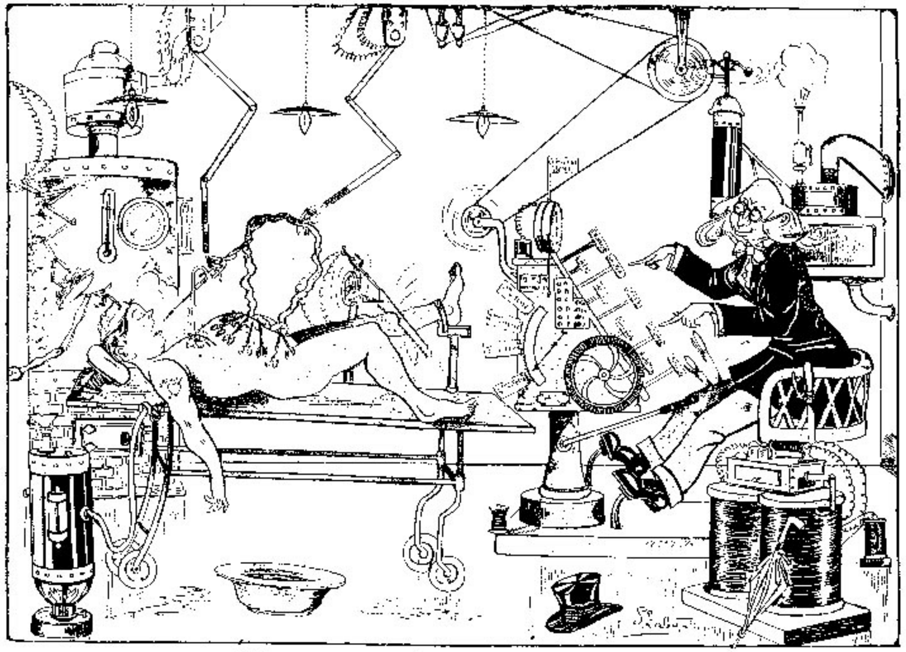
Lecture on haptics/telemanipulation, UNIK4490



UNE SALLE D'OPÉRATIONS EN L'AN 2000

Ole Jakob Elle, PhD
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The Interventional Centre,
Rikshospitalet, Oslo University Hospital
Adjunct Associate Professor
Department of Informatics
University of Oslo

Oslo University Hospital

The Intervention Centre

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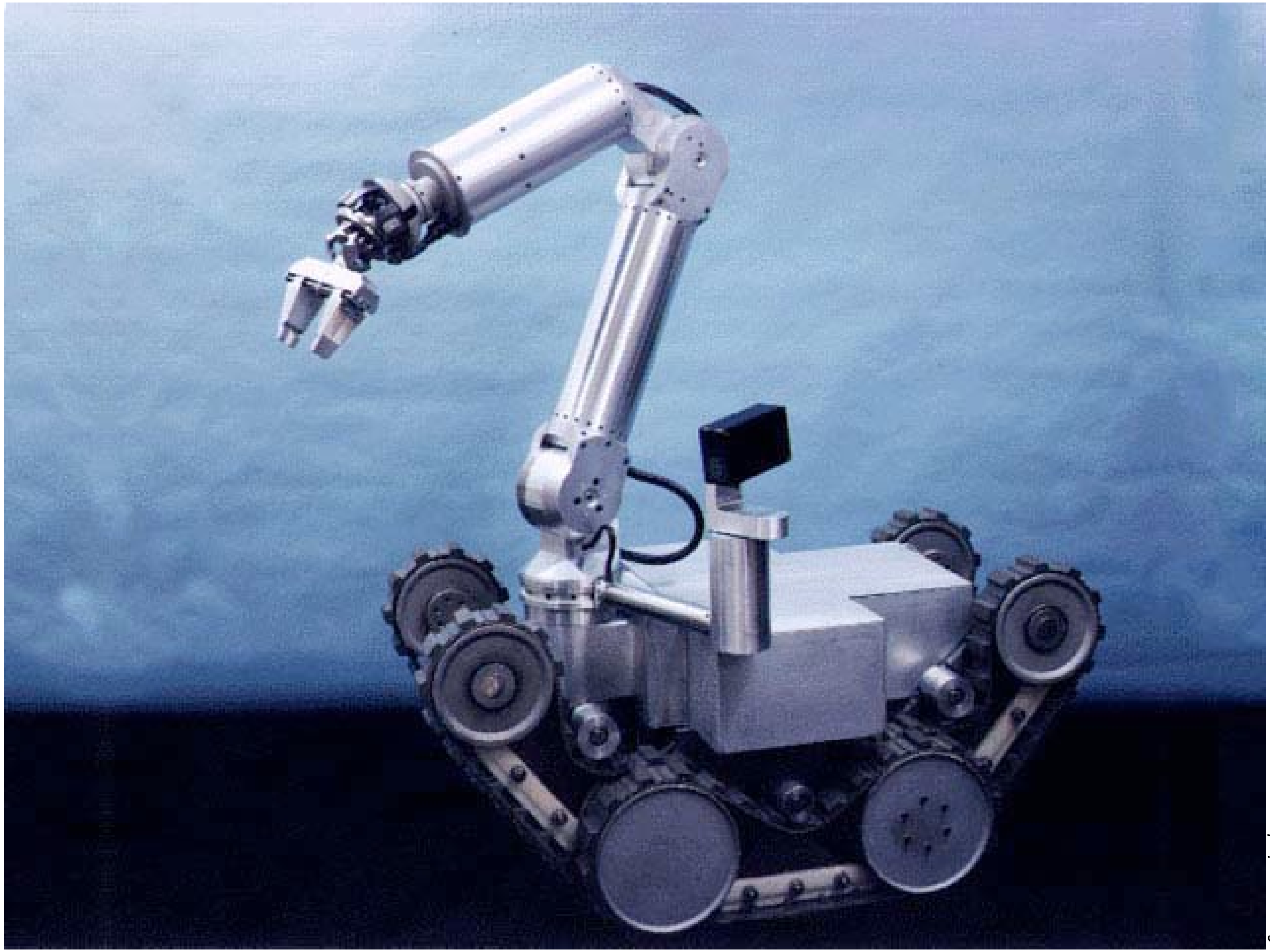
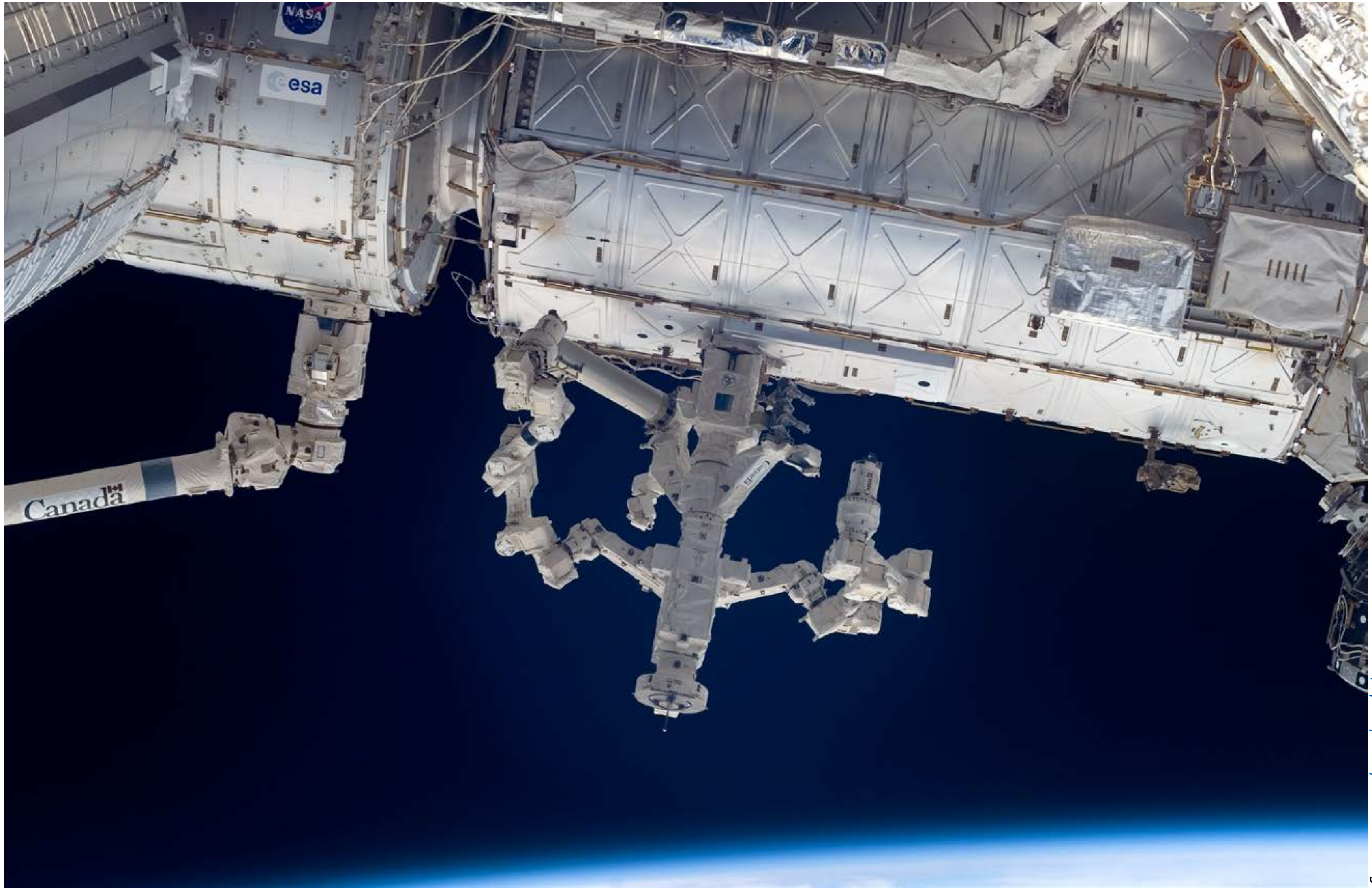
Source: Argonne Na(onal Labs public info office

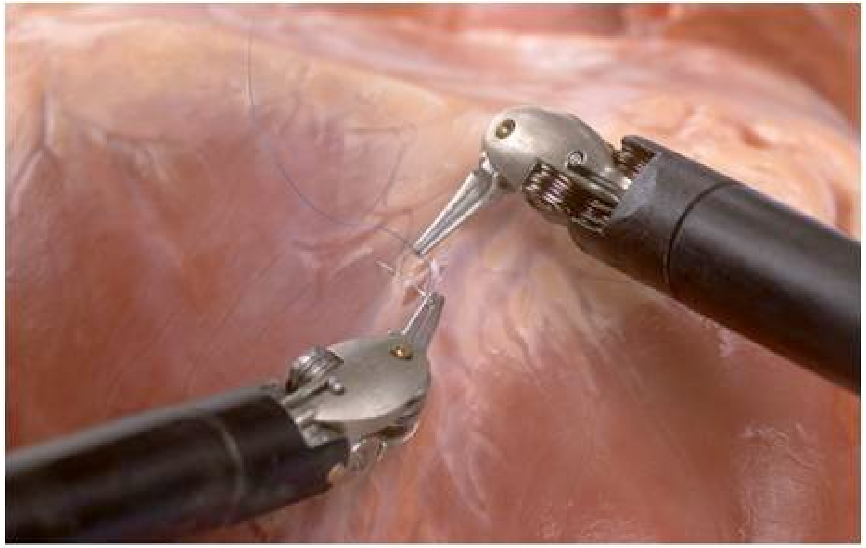


Source: ranier.hq.nasa.gov



Source: www.phys.ncku.edu.tw

Source: www.emeraldinsight.com

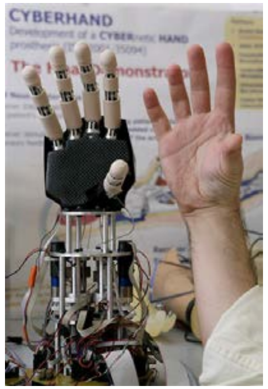


https://youtu.be/7sTfD_mStwE

Source: www.intui)vesurgical.com

Medical Robotics

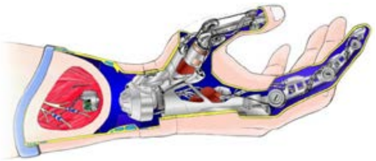
Robotics to assist doctors / surgeons



Assistive technologies

Robots and machines that improve the quality of life of disabled and elderly people, mainly by increasing personal independence

Robotics for surgery, exploration, diagnosis, therapy...



Rehabilitation robotics

Robots and mechatronic tools for clinical therapy in neuro-motor rehabilitation, training…

Robotics to assist people

*3rd SSSR, E. Dombre, Introduction to Surgical Robotics

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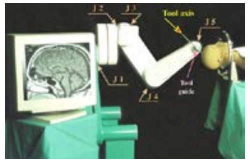
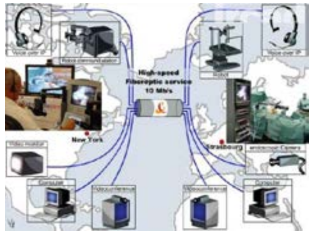
Medical Robotics Timeline





1993:
(MIS)
AESOP 1000
FDA clearance

1997:
(Neurosurgery)
NeuroMate
FDA clearance

1997:
(MIS)
EndoAssist
FDA clearance

1999:
(MIS)
daVinci
CE marking

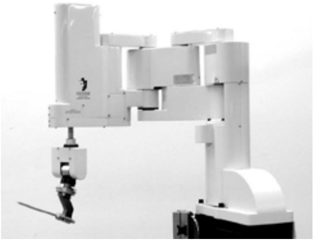
2001:
(MIS)
Operation
Lindbergh

2001:
(Rehabilitation)
Lokomat
CE marking

2004:
(Neurosurgery)
PathFinder
FDA clearance

2003:
(MIS)
LapMan
FDA clearance

| 1990 | 1995 | 2000 | 2005



1994:
(Rehabilitation)
InMotion

1996:
(Orthopedics)
Robodoc
CE marking

1998: (Assistance)
Care-O-Bot

1998:
(MIS)
ZEUS
CE marking

2000: (Assistance)
Guido

2002:
(Rehabilitation)
AutoAmbulator
FDA clearance

2002:
(Orthopedics)
Acrobot

2004:
(Rehabilitation)
Paro

2004:
(Orthopedics
SpineAssist
FDA clearance

2006:
(Rehabilitation)
REO Therapy

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Surgical Robots – degree of autonomy

Da Vinci (Intuitiv Surgical)

Acrobot Sculptor (Acrobot)

AESOP (computerMot

Pathfinder (Prosurgics)

Auxiliary robots

Telesurgical robots

Synergetic Robots

Image-guided surgical robots

Autonomous Robots

-

Degree of Autonomy

+

Automate biopsy (EU:I-SUR)

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Introduction

- Robots have been appearing in operating rooms over the past decade (1994, first robot approved by the FDA).

- Robots are applied in several medical fields: neurosurgery, orthopedics, cardiology, urology…

- Main factors of success:
  - Robots can overcome some of the present problems in Minimally Invasive Surgery (tremors, fulcrum effect, lack of depth perception, …)
  - They can provide new tools (motion scaling, additional degrees of freedom, ….).
  - In general, robots are better than humans in aspects like stability, accuracy, repeatability…
  - Possible to get support/guide in both simple and challenging activities
  - Future automation possibilities

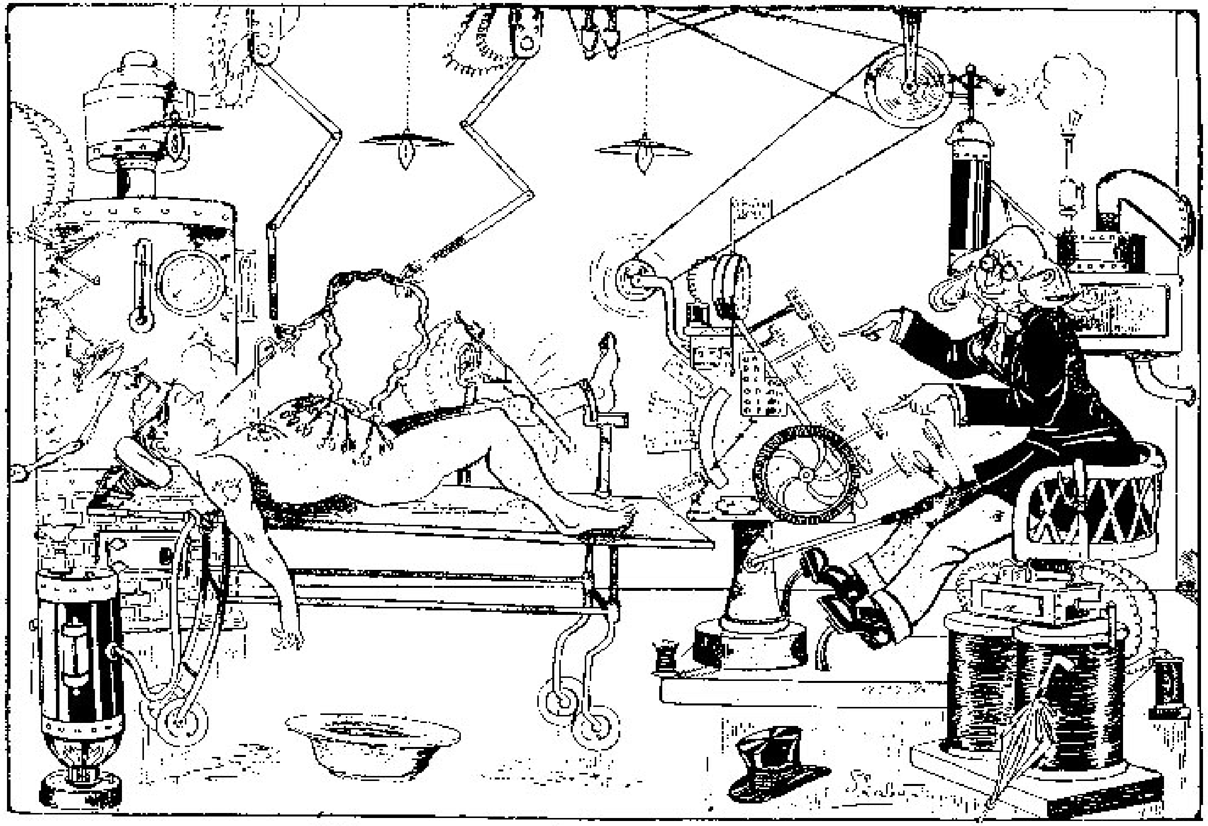
Robotics in surgery

- Surgical robots are still in an early stage of development.
- The number of medical applications where surgical robots can be used is limited.
- Robots are restricted to specific tasks within specific procedures.
- Humans must perform all the preparation tasks.
- Lack of haptic feedback in teleoperated systems.

Robotic surgery

- At the present state of the art, robotic technology for surgical applications can broadly be divided into four main classes
    - Surgical telemanipulators (Remote controlled manipulators)
    - Assisting manipulators (Remote controlled manipulators)
    - Image-guided surgical robots (pre-programmed/industrial robots, laboratory robots)
    - Autonomous/Semi-autonomous robots (automated surgery, drones, tele-echography/ultrasound robot)
    - Mikro-/nanorobots

A French comic drawing from 1914 showing how the artist envisioned the operating room of year 2000



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Surgical telemanipulators

Zeus-
ComputerMotion Inc.

DaVinci-
Intuitive Surgical Inc.

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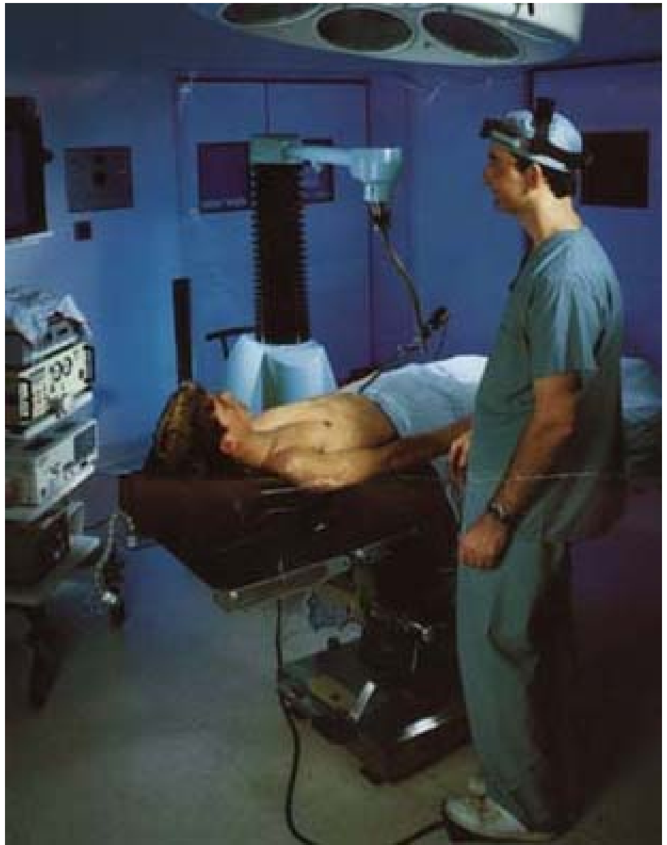
Assisting manipulators – camera holders (remote-controlled)

Aesop-
ComputerMotion Inc.

EndoAssist-
Armstrong HeathCare Lmt.



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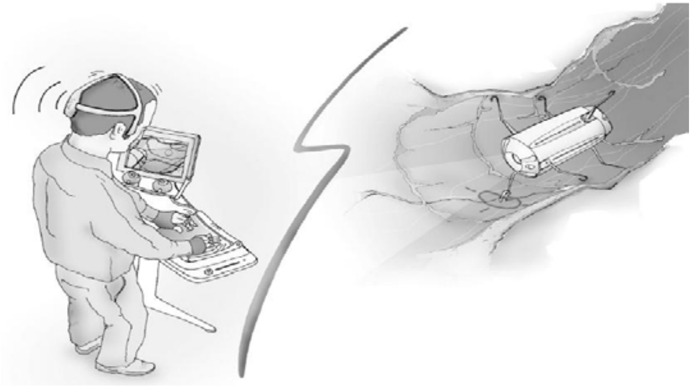
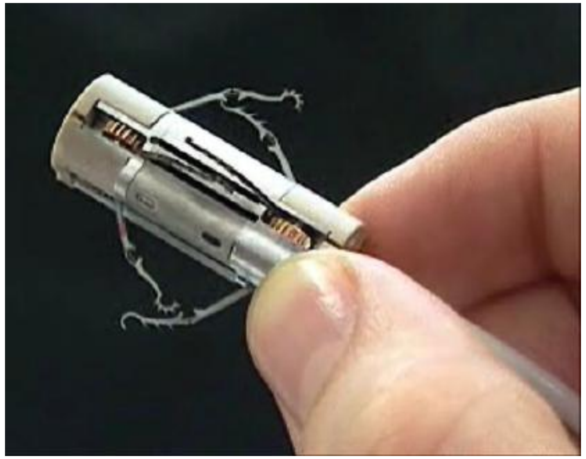
Tele-operated Endoscopic Capsule with Active Locomotion

Scuola Superiore Sant'Anna, Italy (research project)

- Designed for diagnosis and therapy of the large bowel
- Patent filed in 2005
- Long-term goal: The 'all onboard philosophy", a capsule robot able to move around equipped with grippers, optics, sensors, RF modules and drug delivery system
- Focus is currently on locomotion inside the lumen
- 3 prototypes built so far
- Third prototype has eight legs, one CMOS camera and measures 40mm in length



Picture: *www.lirmm.fr/UEE07*



Picture: *iarp06.robot.jussieu.fr*

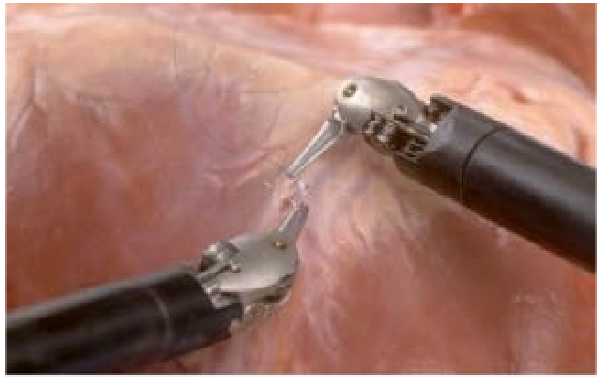
Tele-manipulation in surgery - Advantages

- Higher accuracy - Scaling of operator movements
- Elimination of tremor
- Improved dexterity - Computer controlled dexterity of instruments inside the body
- “Converts” keyhole surgery to open technique (instrument tip control)
- Improved Ergonomics

Teleoperated Robotic Surgery

Interaction Force Estimation

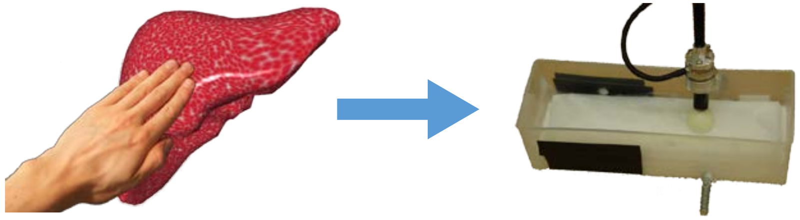
- Sense of touch is lost in current systems
- Lack of haptic feedback largely due to problems associated with measuring interaction forces
- The small diameter of the robotic instruments imposes strict limits on the size of force sensors
- Force sensors also increase instrument cost
- Research suggests that haptic feedback is beneficial in teleoperated robotic surgery
  - Interaction force estimation



Force Sensor Free Bilateral Teleoperation

Sensitivity-Optimized Controller

- Sensitivity-optimized teleoperation controller for surgical palpation tasks
- FSF framework applied to be independent of force sensors
- Evaluation goal: compare controllers before and after FSF transformation
- Objective evaluation: use robot as an operator to avoid all human influence
- Subjective evaluation: use a group of human operators in perception test



Teleoperation with haptic feedback

An Experimental Setup for Teleopera(on

Video Examples

Telesurgical Robots

In a telesurgical system the slave robot reproduces the movements of the surgeon inside the body

Possible improvements

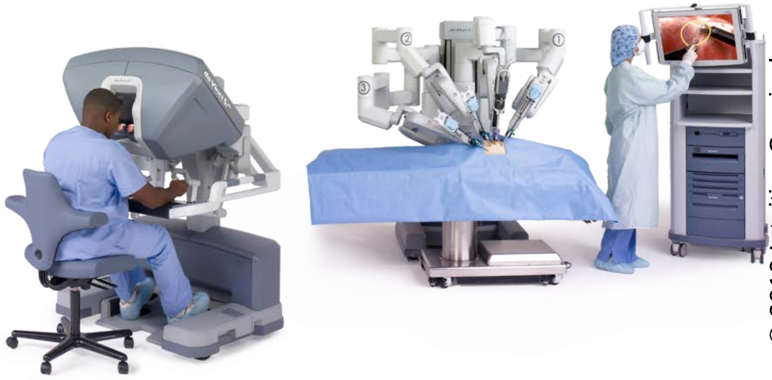
Haptic feedback

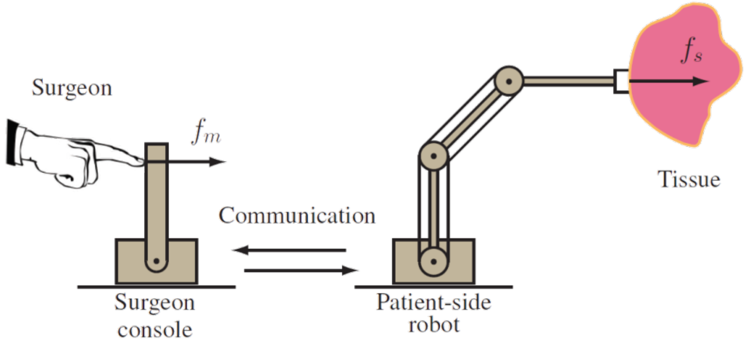
Haptic Guidance

Autonomous functions

Teleoperated Robotic Surgery
Concept & Benefits

- Minimally invasive surgery
- Endoscopic instruments replaced by a robot operated from a separate console
- Wrist-like dexterity inside patient
- Motion scaling for increased precision
- Filtering of surgeon tremor
- Future potential for remote surgery





Teleoperated Robotic Surgery

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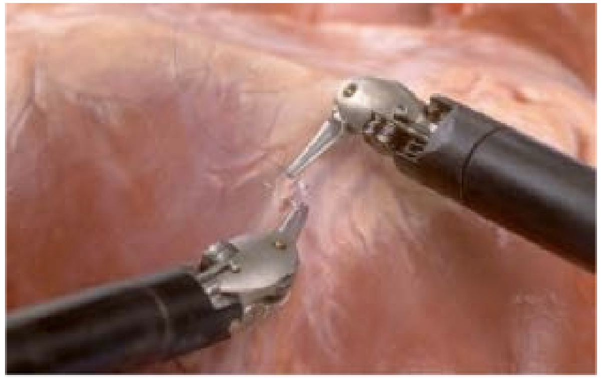


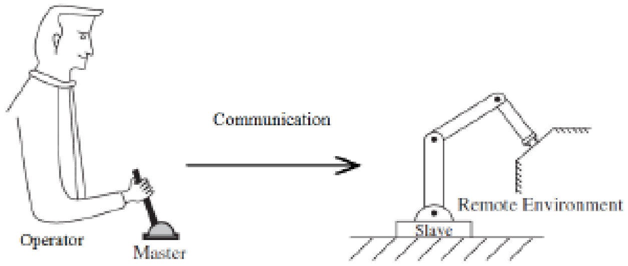
Introduction to Teleoperation

What is teleoperation?

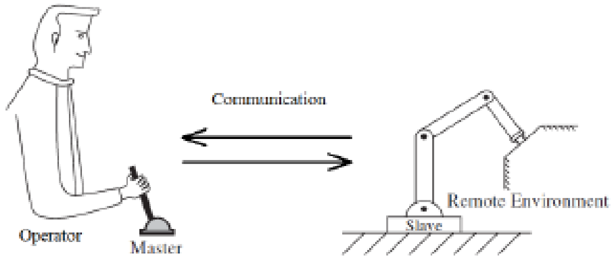
Definition of teleoperation (www.wikipedia.org):

"… operation of a machine at a distance …"

- Unilateral teleoperation:



- Bilateral teleoperation:



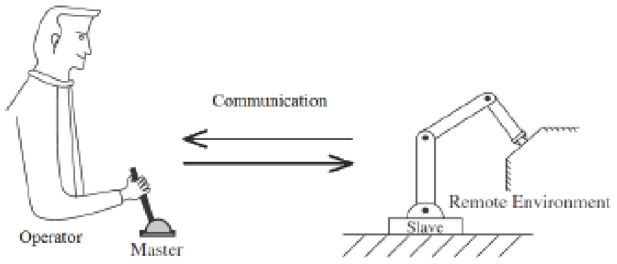
Teleoperation Control Concepts
Modeling a 1-DoF Linear Teleoperator

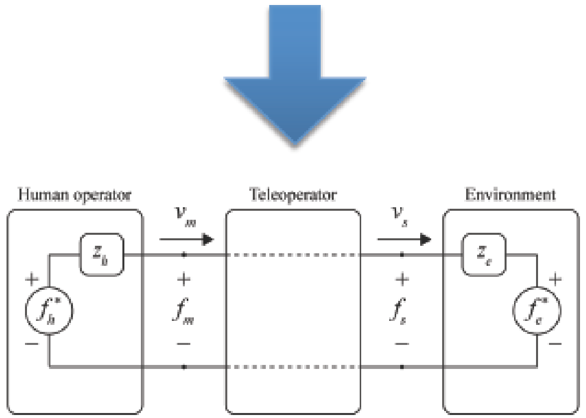
- The two-port network model
  - Energy ($P = fv$) exchange takes place at two locations, or ports
- The hybrid matrix representation

$$\begin{bmatrix} f_m \\ -v_s \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} v_m \\ f_s \end{bmatrix} = H \begin{bmatrix} v_m \\ f_s \end{bmatrix}$$

- The ideal (transparent) teleoperator

$$\begin{matrix} f_m = f_s \\ v_m = v_s \end{matrix} \quad \Rightarrow \quad H = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$





Contact Force Estimation

Relation to Teleoperation in Surgery

- Research suggests that it would be favorable to have force feedback in robotic tele-surgical systems
- Realistic force feedback in bilateral teleoperation requires the knowledge of contact forces
- The use of force sensors in robotic minimally invasive surgery introduces challenges related to
  - Size and cost
  - Sterilizability and disposability
  - Wiring and electronics
  - Noise and bandwidth

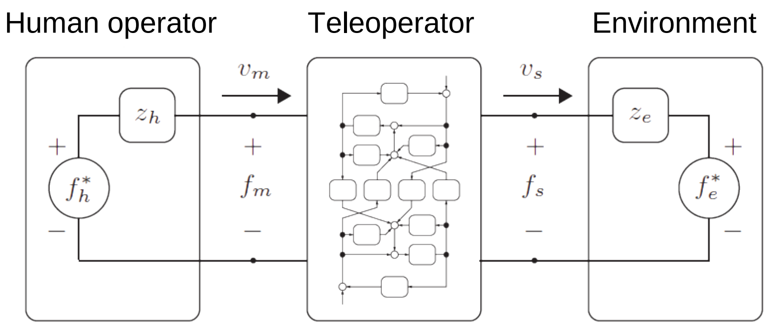
Source: www.intuitivesurgical.com

Source: www.ati-ia.com

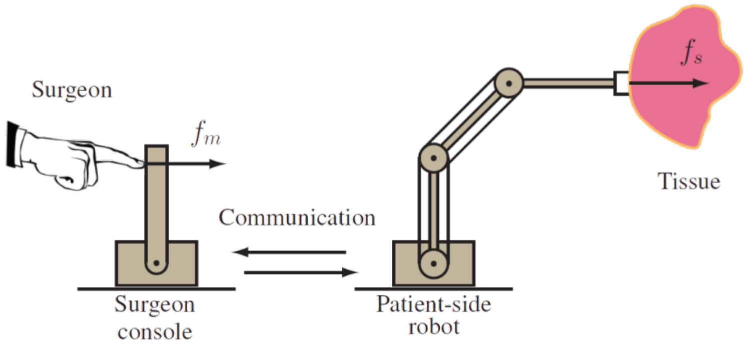
Force Sensor Free Bilateral Teleoperation
Design Framework

- Two-port network modeling
- Impedance matrix representation

$$\begin{bmatrix} f_m \\ f_s \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} v_m \\ -v_s \end{bmatrix}$$

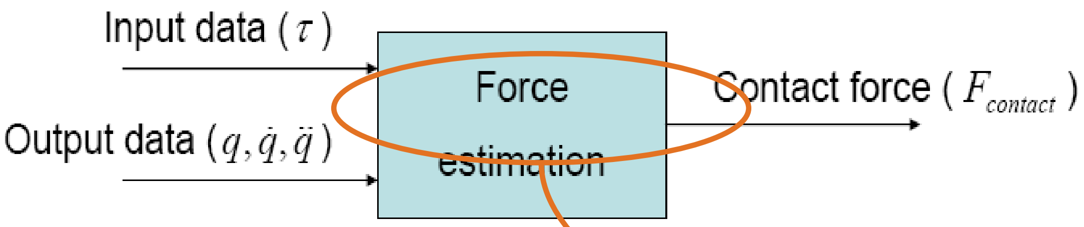


- Provides a means of estimating forces
- *Force Sensor Free* (FSF) design framework
- Automatically transforms a controller that needs force sensing into an equivalent controller independent of force sensing



Estimation of the Contact Forces

- The use of force sensors in surgery requires:
  - The sensor must be small enough
  - Sterilization or disposability
  - Additional wiring and electronics
- An alternative approach is the estimation of the contact forces:



It requires a good model of the robot dynamics and friction forces

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + N(q) + \tau_f(\dot{q}) = \tau$$

Haptics – Sense of touch

- Haptic
  - Kinaestehtic (force/position) or Tactile
  - Direct force/torque measurements or virtual force/torque

Haptic Guidance

Generation of virtual forces with the objective of guiding the movements of the surgeon and helping him to complete the tasks.

Advantages

with respect to teleoperation

- Increase speed and precision
- Reduce operator workload
- Reduce effects of time delays

with respect to autonomous robots

- Increase the surgeon confidence
- Small registration errors can be corrected manually

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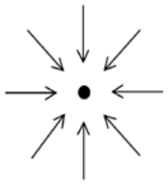
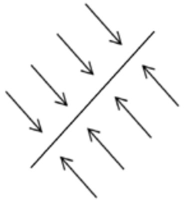
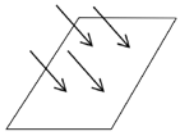
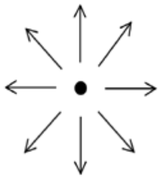
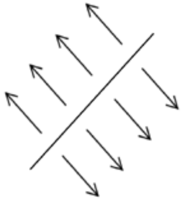
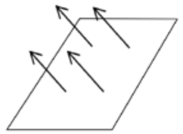
Types of Haptic Guidance and Active Constraint

- Considering the Cartesian position of the manipulator and the task to be performed

	3 motion constraints	**2 motion constraints**	**1 motion constraint**
Attractive forces (guidance)			
Repulsive forces (no-go zones or active constraint)			

- Considering other parameters:
  - Relative velocity between master and slave devices
  - Workspaces and singularities of the manipulators.

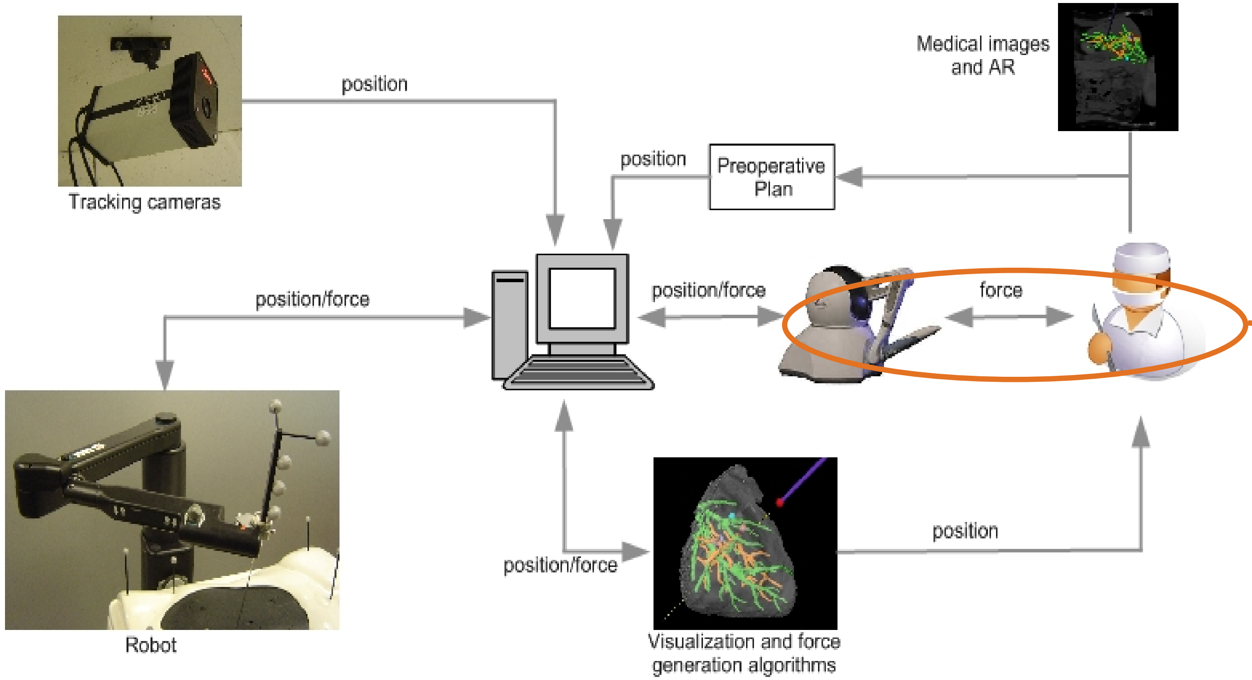
Force Generation Algorithms

- Two basics steps:
  - Direction of the force: Minimum distance between the real point and the constraint.
  - Magnitude of the force:

$$\mathbf{f}_g = \mathbf{K}_p \mathbf{e}_k + \mathbf{K}_d (\mathbf{e}_k - \mathbf{e}_{k-1})$$

- Two approaches:
  - *Constraint in the slave side:* The forces are generated taking into account the position of the robot.
  - *Constraint in the master side:* The forces are generated considering the position of the haptic and then the position is sent to the robot.

Block Diagram



The surgeon feels correcting forces when deviations between the real position of the robot and the preoperative plan are detected

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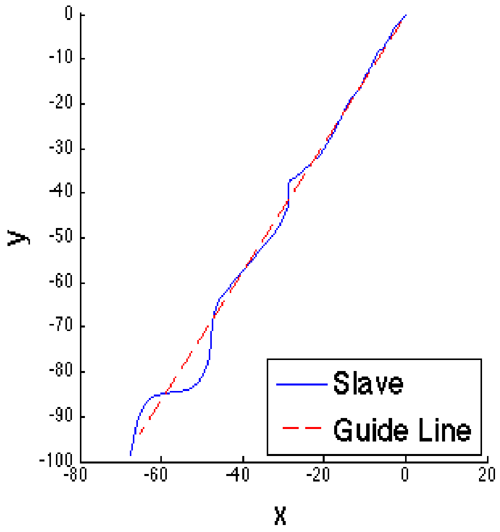
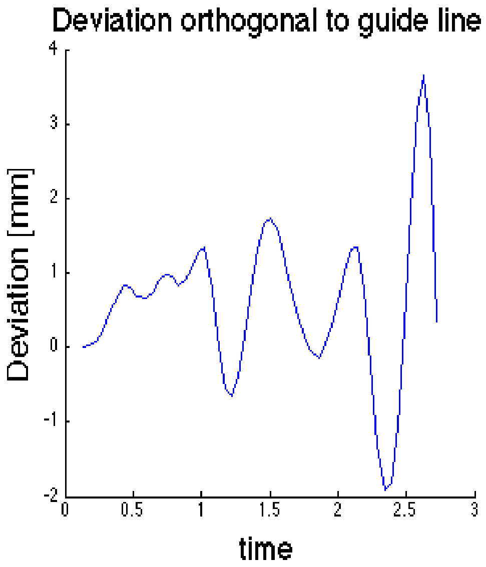
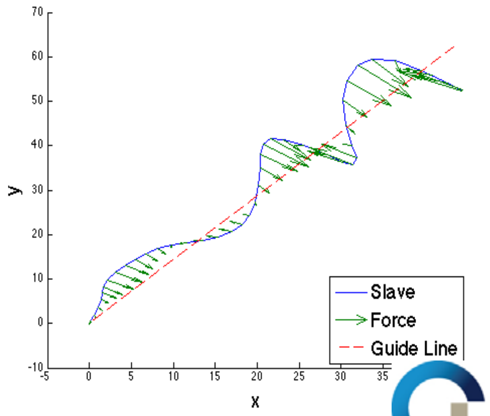
Results – Constraints in the slave side

position

force







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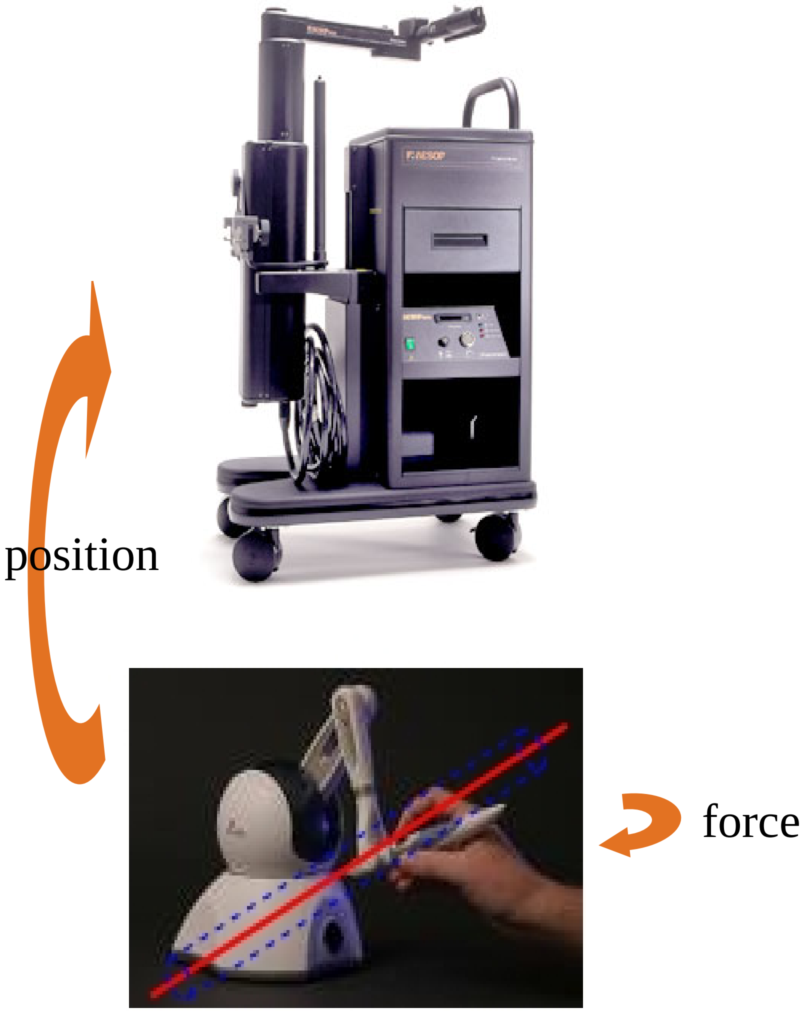
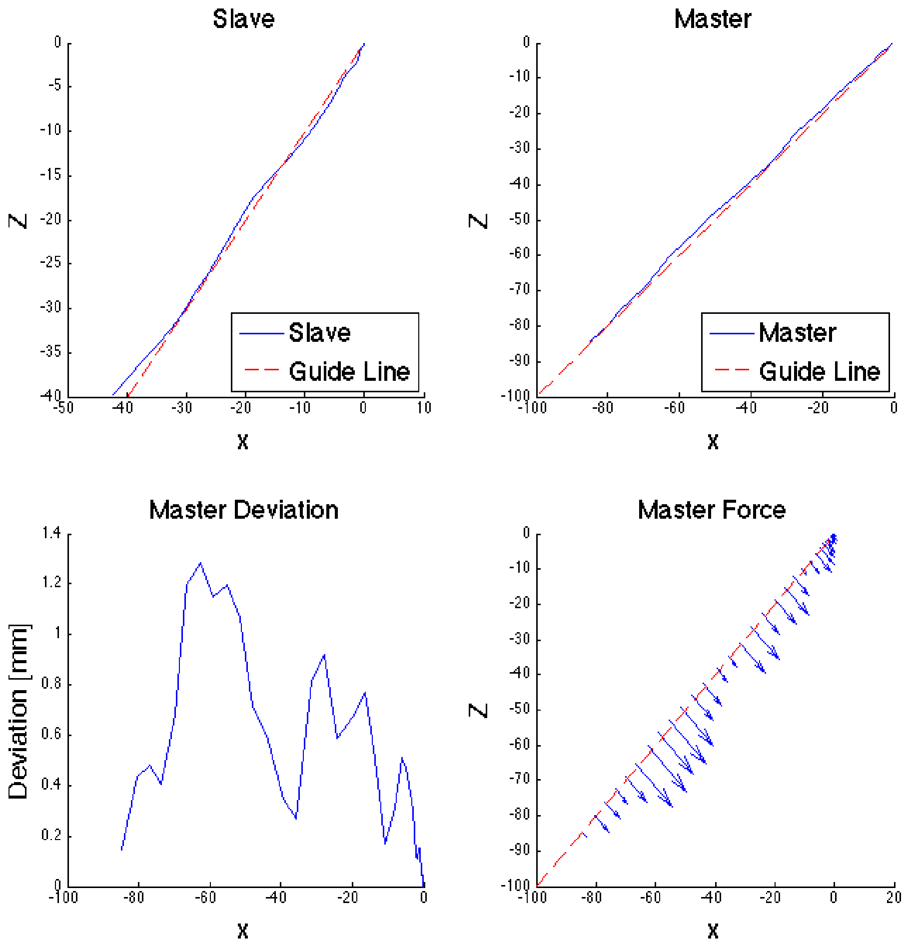
Results – Constraints in the master side





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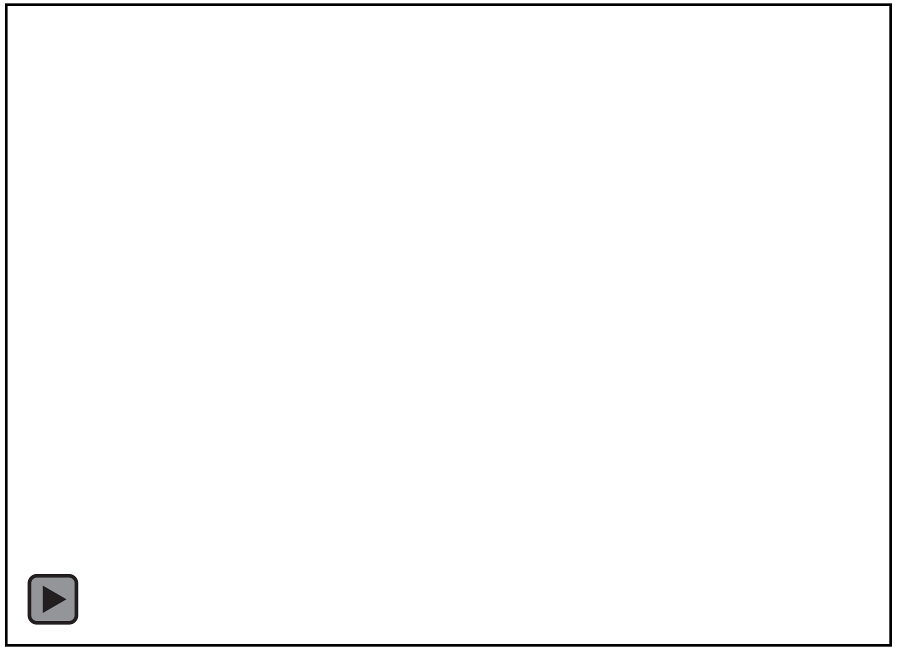
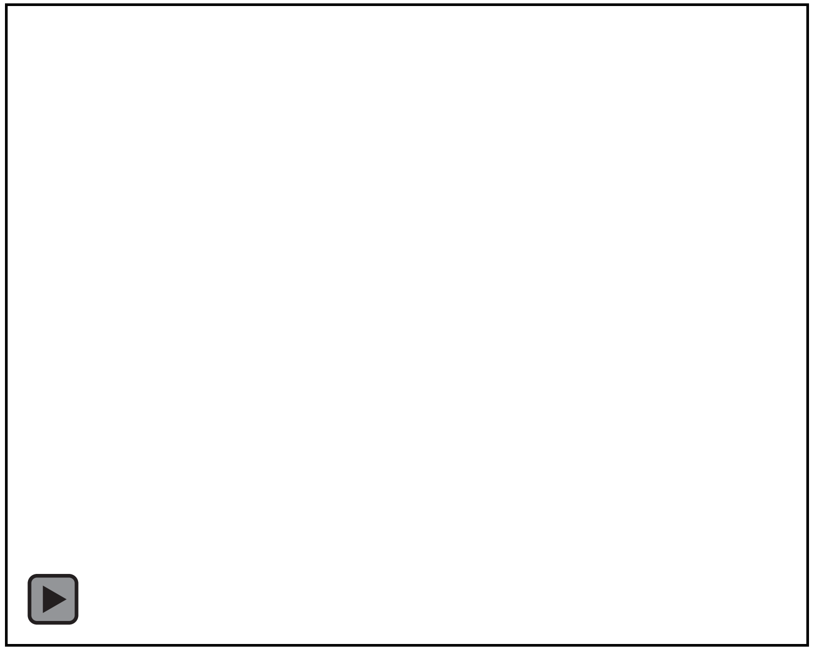
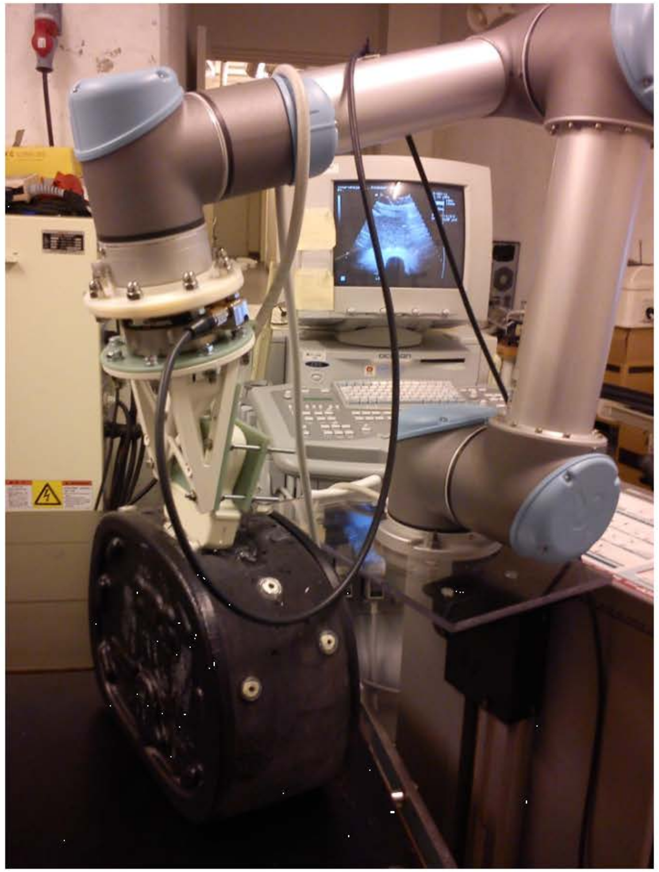
Demo Robot-Kinect interaction





Robotsystem)for)teleŒkkografi)

- UR5)robot)fra) Universal)Robots)
- Kra_sensor)fra)ATIŒA)
- Bruker)en)vanlig) ultralydmaskin)
- Video)hentes)inn)med) en)frame)grabber)
- Proben)monteres)på) roboten)

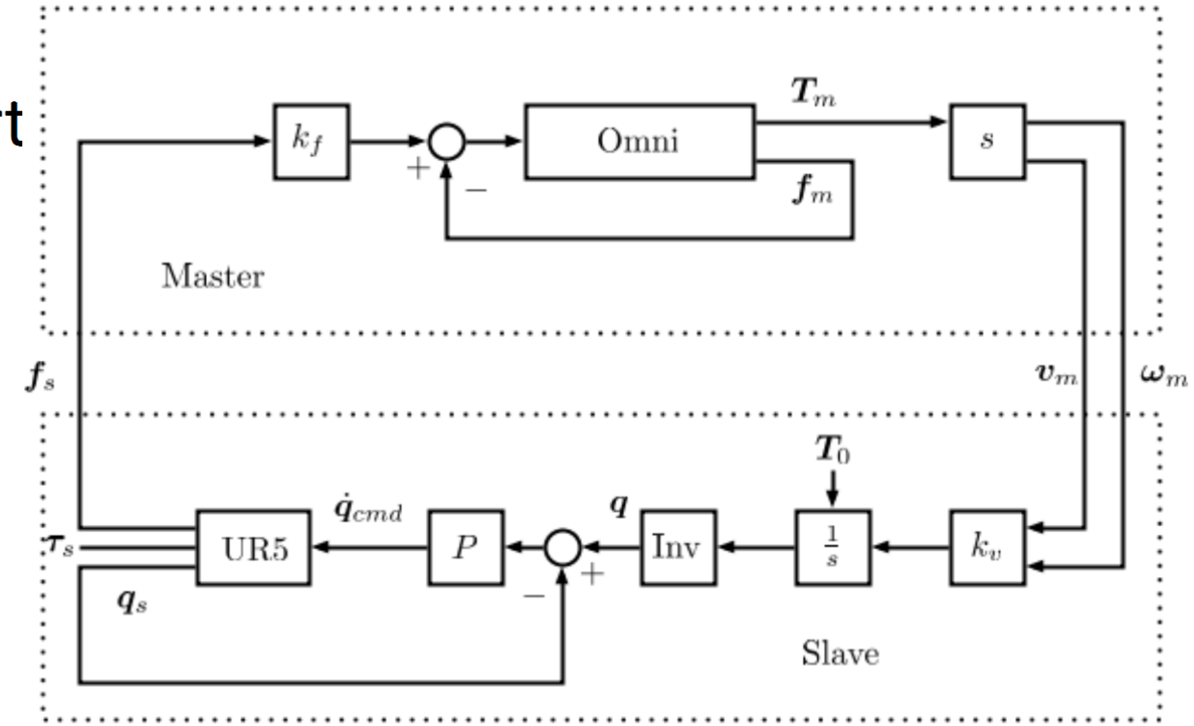


Hap=kk)

- Brukeren)føler)kra_en) som)roboten)bruker) på)pasienten)
- Phantom)Omni)som) master)
- UR5)som)slave)

Hap=kk)

- Forward)flow)
- Master)kra_styrt
  - 3)DoF)
- Slave)fartsstyrt)
  - 6)DoF)



Innslag på NRK – nett (vår 2015):

http://www.nrk.no/magasin/robotlegene-kommer_-1.12358595

- Software/system er lisensiert av MEKTRON fra OUS-IVS og IFI-UIO (Nov 2014)
- Mektron skal ta dette produktet ut I markedet sommeren 2017

Oslo universitetssykehus

Oslo universitetssykehus eies av Helse Sør-Øst og består av de tidligere helseforetakene Aker, Rikshospitalet og Ullevål. Oslo universitetssykehus leverer spesialisthelsetjenester og ivaretar både lands-, regions- og lokalfunksjoner. Sykehuset er landets største med cirka 20 000 ansatte og har et budsjett på 18 milliarder kroner. Oslo universitetssykehus står for en betydelig andel av medisinsk forskning og utdanning av helsepersonell i Norge.

HELSE SØR-ØST

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