Human Robot Interaction

Advanced Multi-Modal User Interfaces

/> Albert Hernansanz, UPC

Index

1. Basic rules and concepts in UI

Usability Goals and Measures in GUI (valid for generic UI)

- **Time to learn.** How long does it take for typical members of the user community to learn how to use the actions relevant to a set of tasks?
- **Speed of performance.** How long does it take to carry out the benchmark tasks?
- **Rate of errors by users.** How many and what kinds of errors do people make in carrying out the benchmark tasks?
- **Retention over time.** How well do users maintain their knowledge after an hour, a day, or a week?.
- **Subjective satisfaction.** How much did users like using various aspects of the interface?

Shneiderman, Ben, et al. Designing the User Interface: Strategies for Effective Human-Computer Interaction, Global Edition, Pearson Education Limited, 2017. ProQuest Ebook Central

Design rules for effective 3D interfaces

- Use occlusion, shadows, perspective, and other 3-D techniques carefully.
- Minimize the number of navigation steps required for users to accomplish their tasks.
- Keep text readable (better rendering, good contrast with background, and no more than 30-degree tilt).
- Avoid unnecessary visual clutter, distraction, contrast shifts, and reflections.
- Simplify user movement (keep movements planar, avoid surprises like going through walls).
- Prevent errors (that is, create surgical tools that cut only where needed).
- Simplify object movement (facilitate docking, follow predictable paths, limit rotation).
- Organize groups of items in aligned structures to allow rapid visual search.
- Enable users to construct visual groups to support spatial recall (placing items in corners or tinted areas).

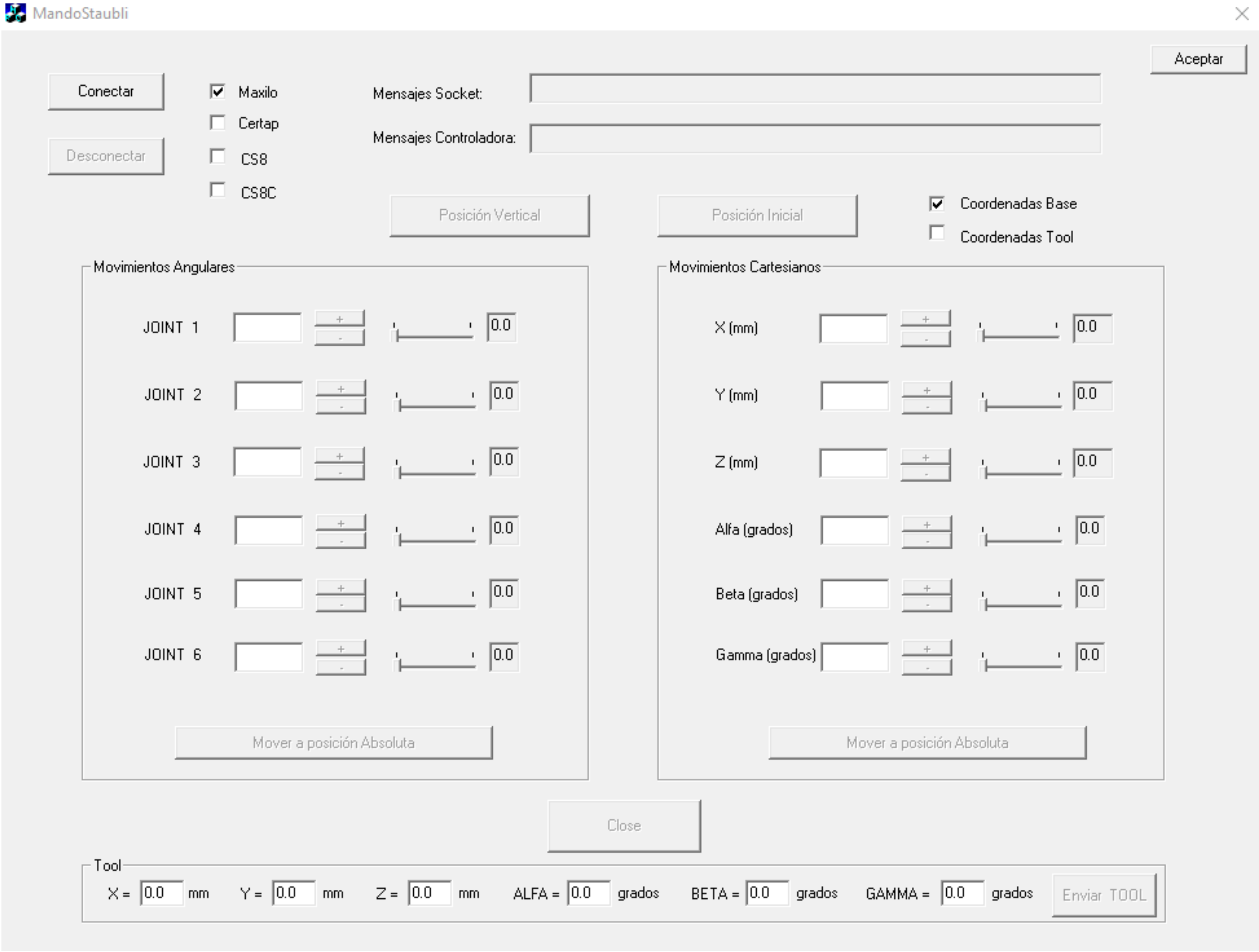
Shneiderman, Ben, et al. Designing the User Interface: Strategies for Effective Human-Computer Interaction, Global Edition, Pearson Education Limited, 2017. ProQuest Ebook Central

Basic rules and concepts in UI

Best practices in programming

Design based on task requirements and user type

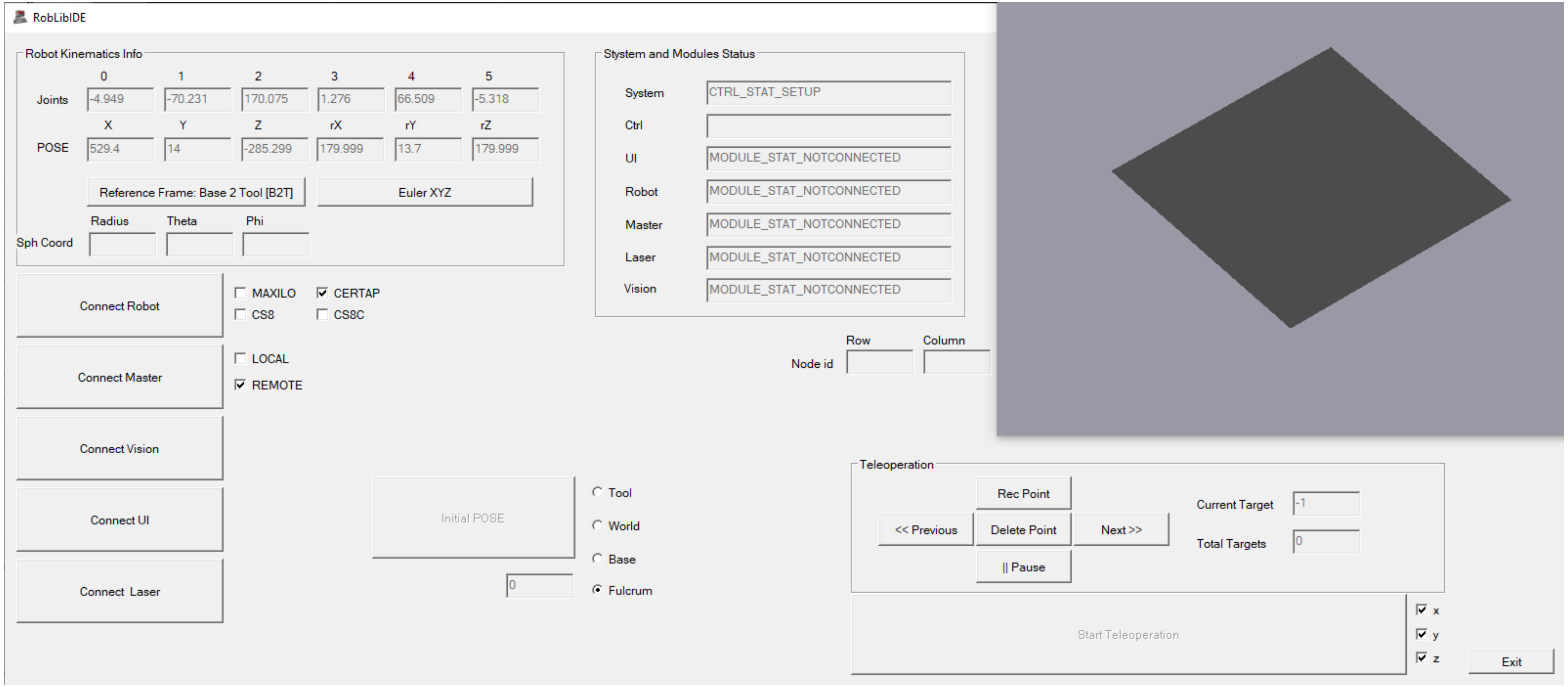
- Example 1: Virtual teach pendant for a 6DoF robot // Usr: Expert on robotics



Basic rules and concepts in UI

Design based on task requirements and user type

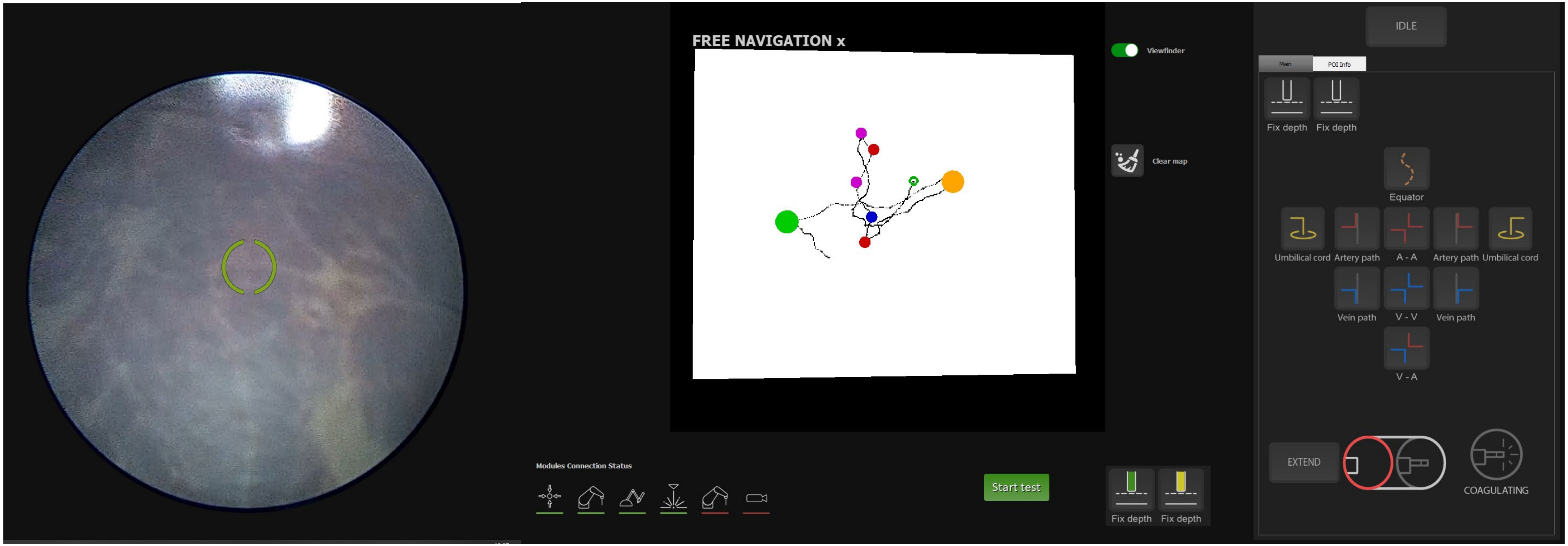
- Example 2: Main teleoperation control // Usr: Expert on robotics



Basic rules and concepts in UI

Design based on task requirements and user type

- Example 3: Teleoperator view // Usr: Surgeon



Example of a surgery planning interface

Software to define virtual fixtures to protect skull and brain and guide driller during surgery

- **First attempt: Fail**
  - First attempt without surgeons collaboration.
  - Spectacular 3D reconstruction and planning.
  - Result: unuseful for end users

- **Second attempt: Success**
  - Surgeon collaboration from the beginning.
  - End users define how their workflow and how manage with data
  - Result: useful for end users

Example of a surgery planning interface

2. Augmented and Virtual Reality in surgery

From real to virtual environments

- Reality-virtuality continuum

Milgram and Kishino in 1994.

Augmented reality

- AR: enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device

Virtual Reality

- VR: computer-generated environments for you to interact with, and be immersed in.

- **AR**: Fusion information. Real image + projection of synthetic information
- **VR**: Complete virtual environment synthetically generated

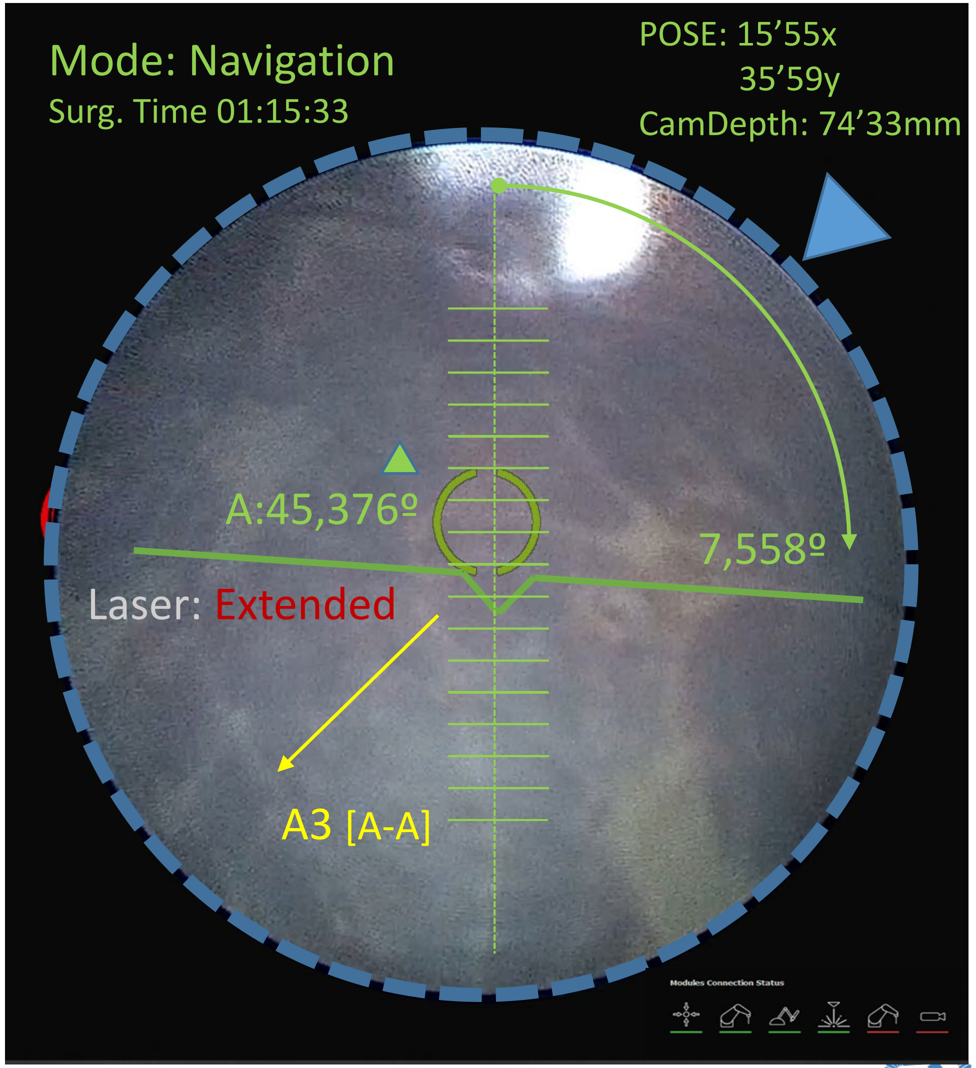
AR in surgery

- Benefits
  - Provide anatomical visual information avoiding physical occlusions

- Drawbacks
  - Depending on the amount of information and its visualization, can disturb surgeons
  - Discrepancies between simulated model and reality (e.g. complex dynamics like internal tissue deformation)

Common mistake: too much information

- More information != better understanding
- Too much information disturbs user from main task
- Focus the attention of the users on what is really important.
- Provide auxiliary information out of the main focus



Augmented reality

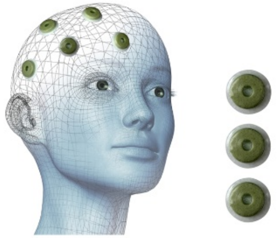
- The reality of augmented reality in surgery
  1. Information must match with reality: accurate register methodology
  2. Information should not disturb surgeons

  - Useful in orthopedic surgery: rigid structures, easy to register

  - Difficult in deformable tissues:
    - Noticeable variations between pre-operative information vs during surgery (e.g. deformation of organs in laparoscopy due to pressure exerted by insufflated gas)
    - Dynamic models of deformable tissues and organs is difficult to compute, even more in real time

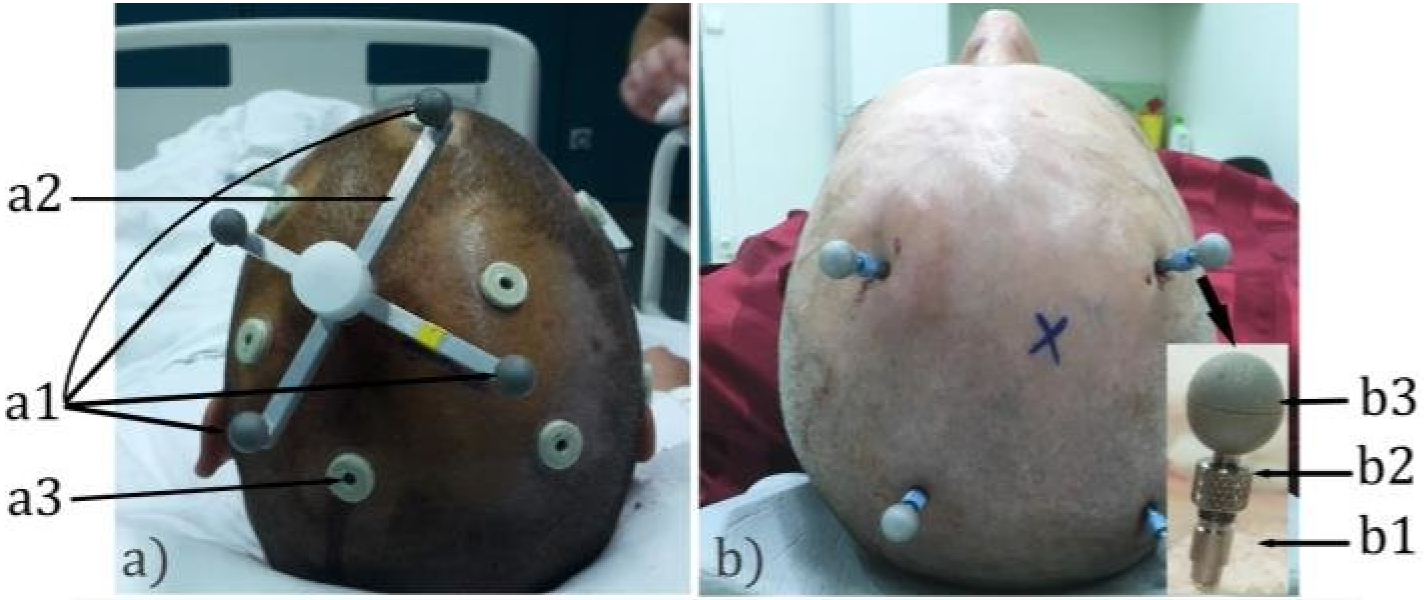
Augmented and Virtual Reality in surgery

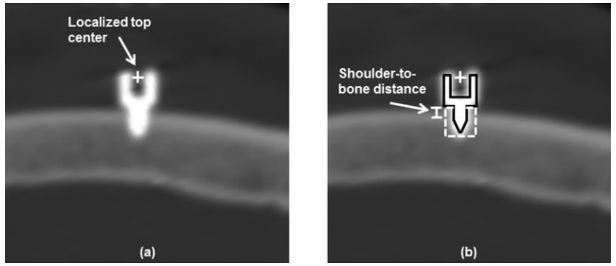
Register during surgery

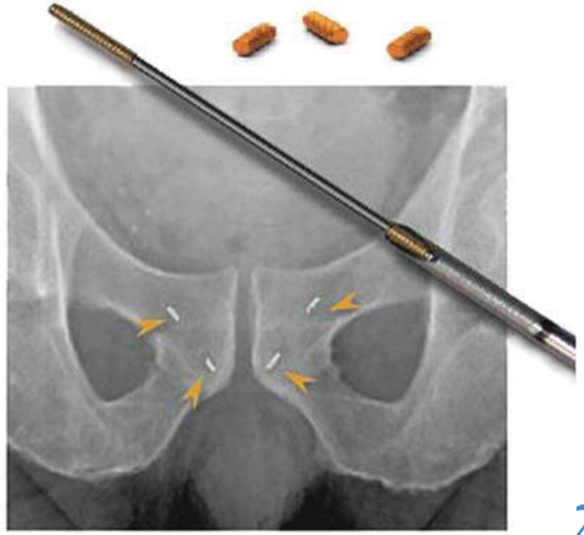


- Match pre-operative information with reality
  1. Initialization of register: set common frames (reality and pre-operative data)
  2. Real time and accurate tracking if there is the possibility of real scenario movement

- Fiducial markers: markers easy to detect in both
  - Pre-operative data acquisition
  - During surgery

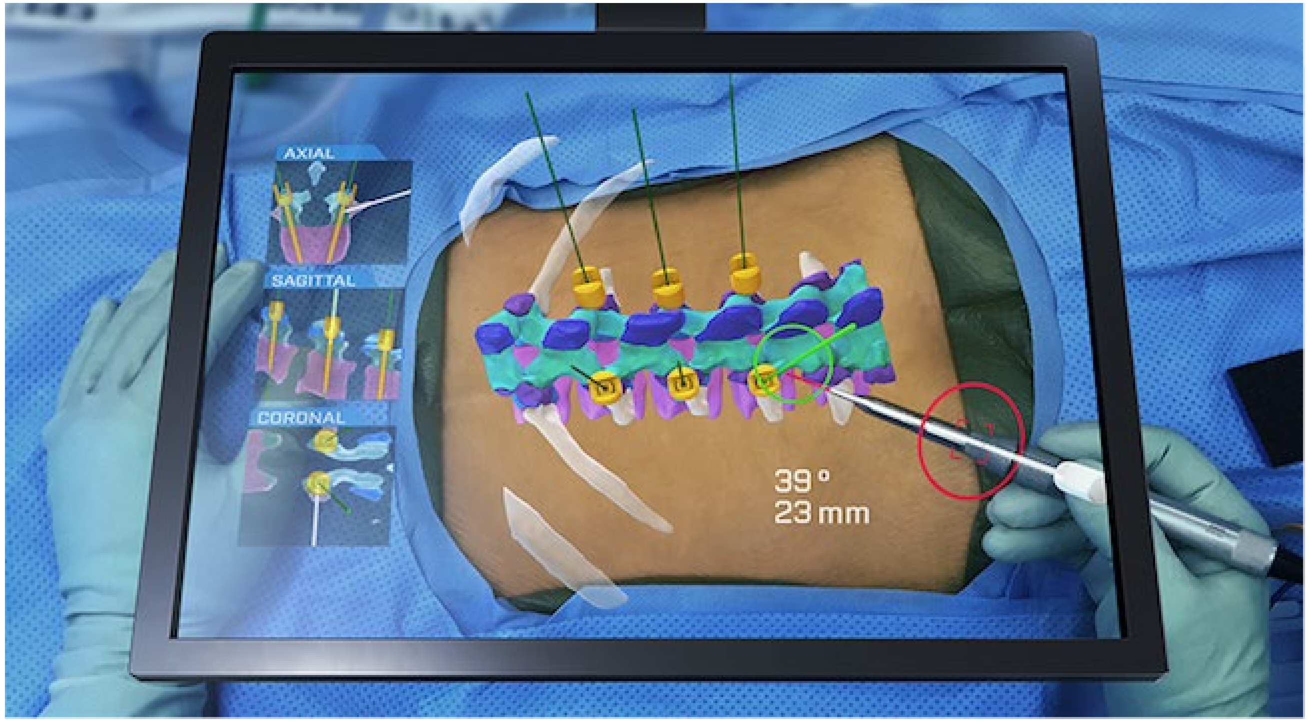






Example in rigid organs

- pre-operative medical image projected over the patient



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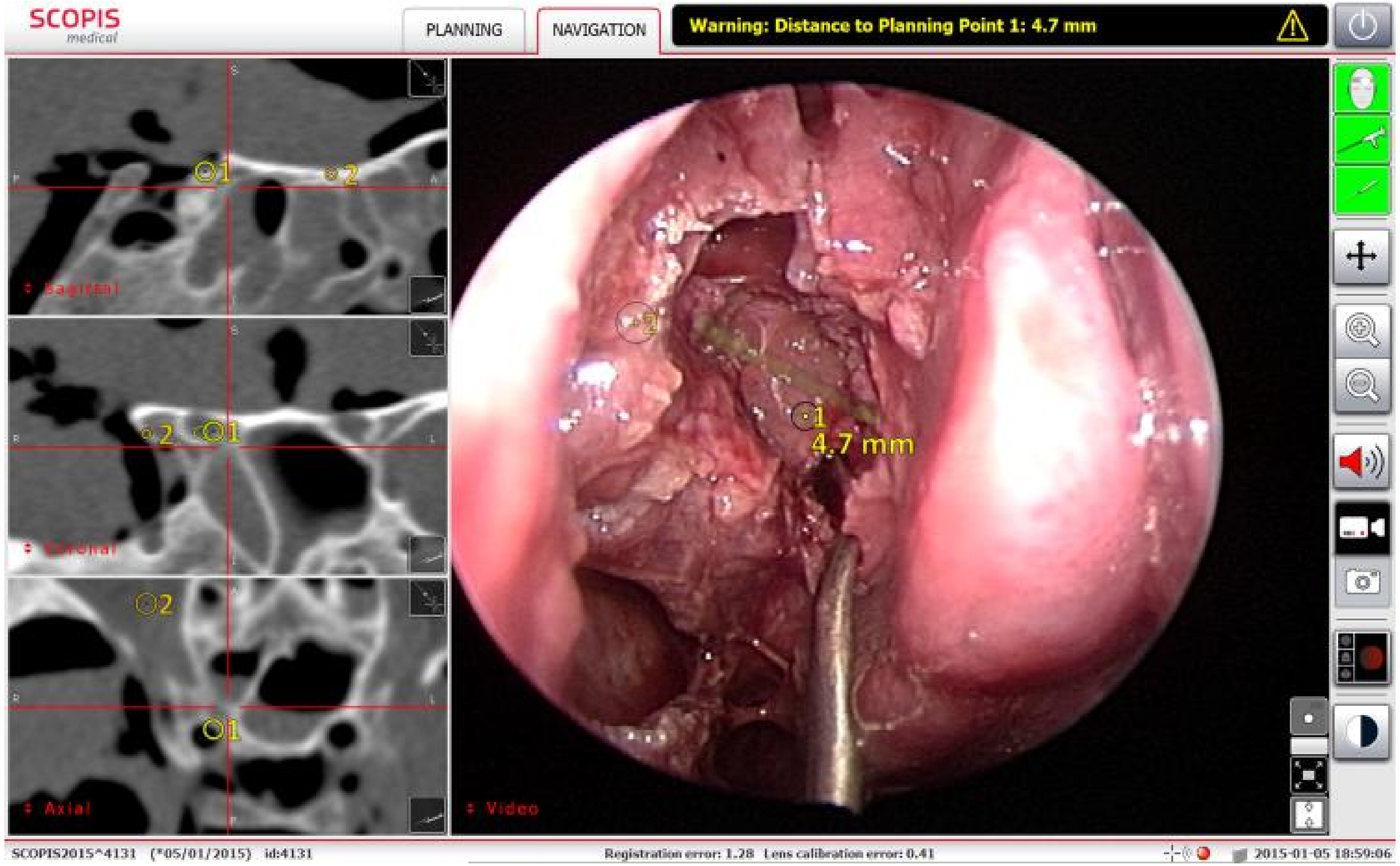
Example: automatic detection and indication of polyps

Optic nerve is projected as yellow structure oriented obliquely in the center of this image



Citardi MJ, Agbetoba A, Bigcas JL, Luong A. Augmented reality for endoscopic sinus surgery with surgical navigation: a cadaver study. Int Forum Allergy Rhinol. 2016 May;6(5):523-8. doi: 10.1002/alr.21702. Epub 2015 Dec 31

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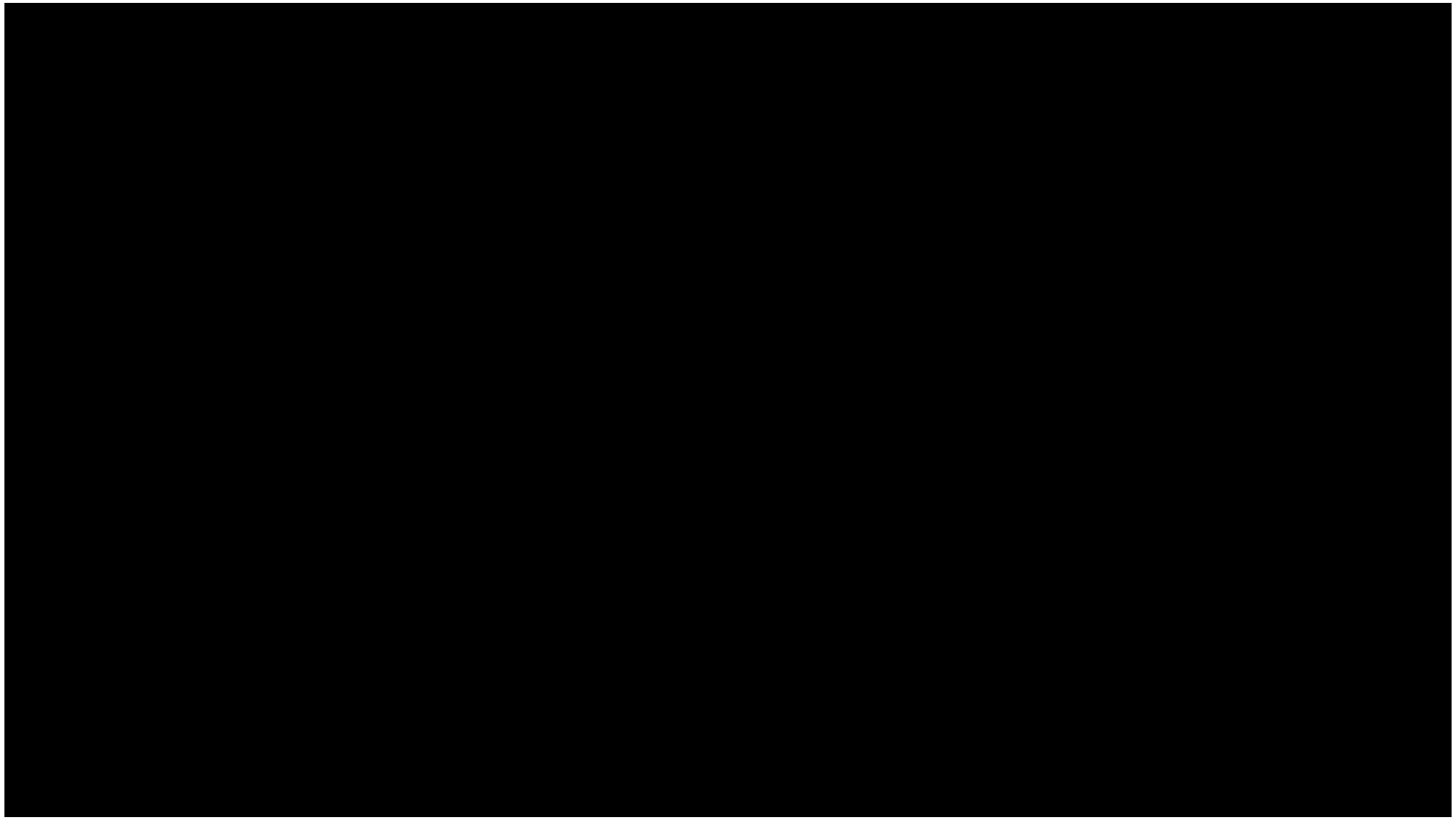
Example in deformable organs

- pre-operative medical image projected over the patient



3. Case study of UI (Master console) in RMIS

Case study of UI in RMIS: da Vinci

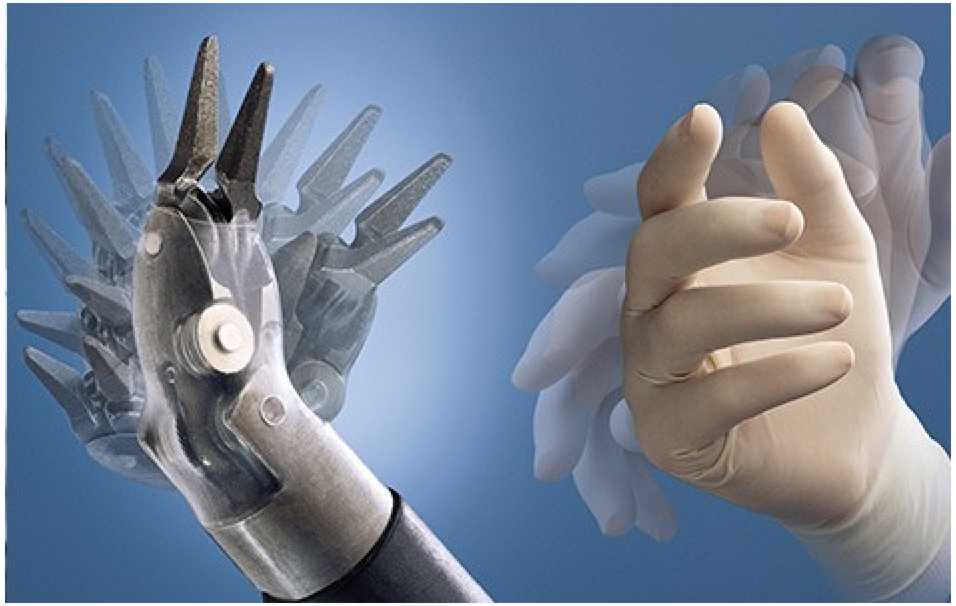
Description and discussion of a UI

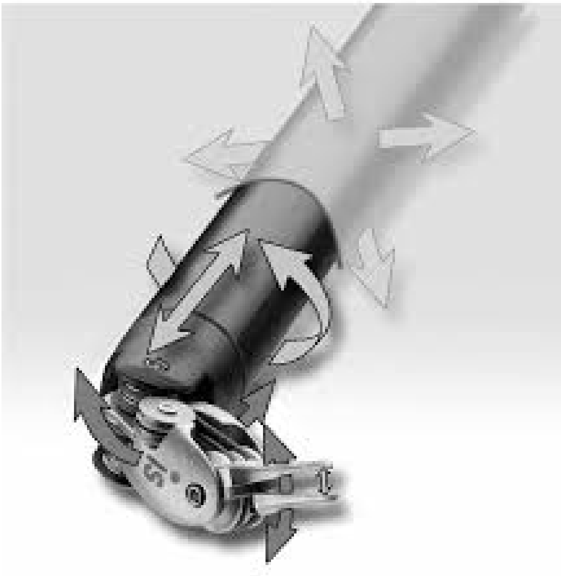
- Fixed head: prevent expected change of POV moving head
- Cannot see hands for a better abstraction in hands-tool correspondence
- Forearms are supported to increase accuracy
- High quality stereo vision for a more immersive experience

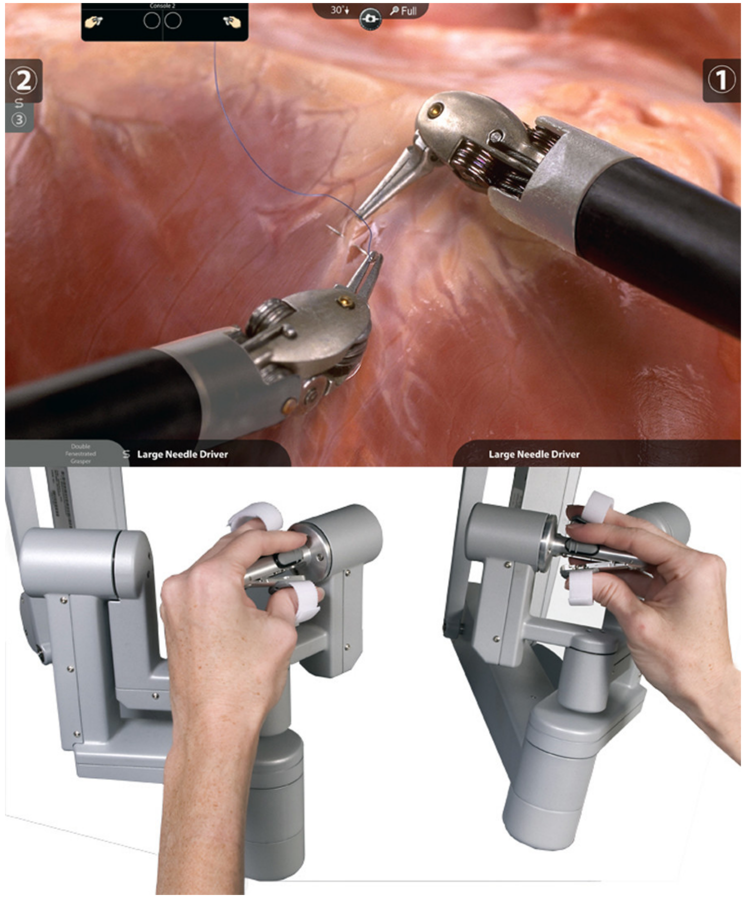
Description and discussion of a UI

- Tools are designed following human wrist DOFs and movements

- Tools imitate grip with two fingers





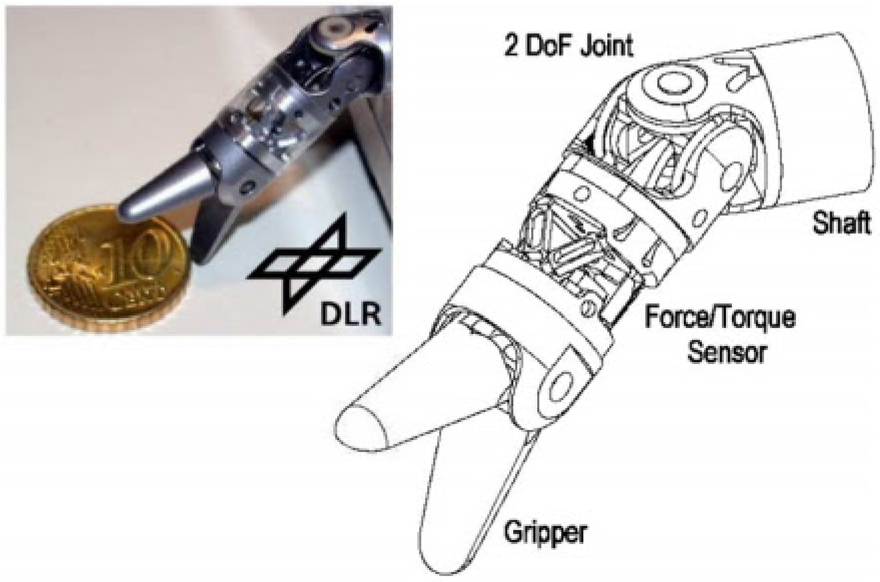


Description and discussion of a UI

- Drawback #1: Lose of tactile information

- Solution 1: Use force/torque sensors between robot and surgical tool.
- Problem: Disturbances in measures due to
  - Tool deformation
  - Trocar contribution

- Solution 2: Equip tools with force/torque sensors
- Problem:
  - Mechanical complexity and price
  - Use of electricity for coagulation

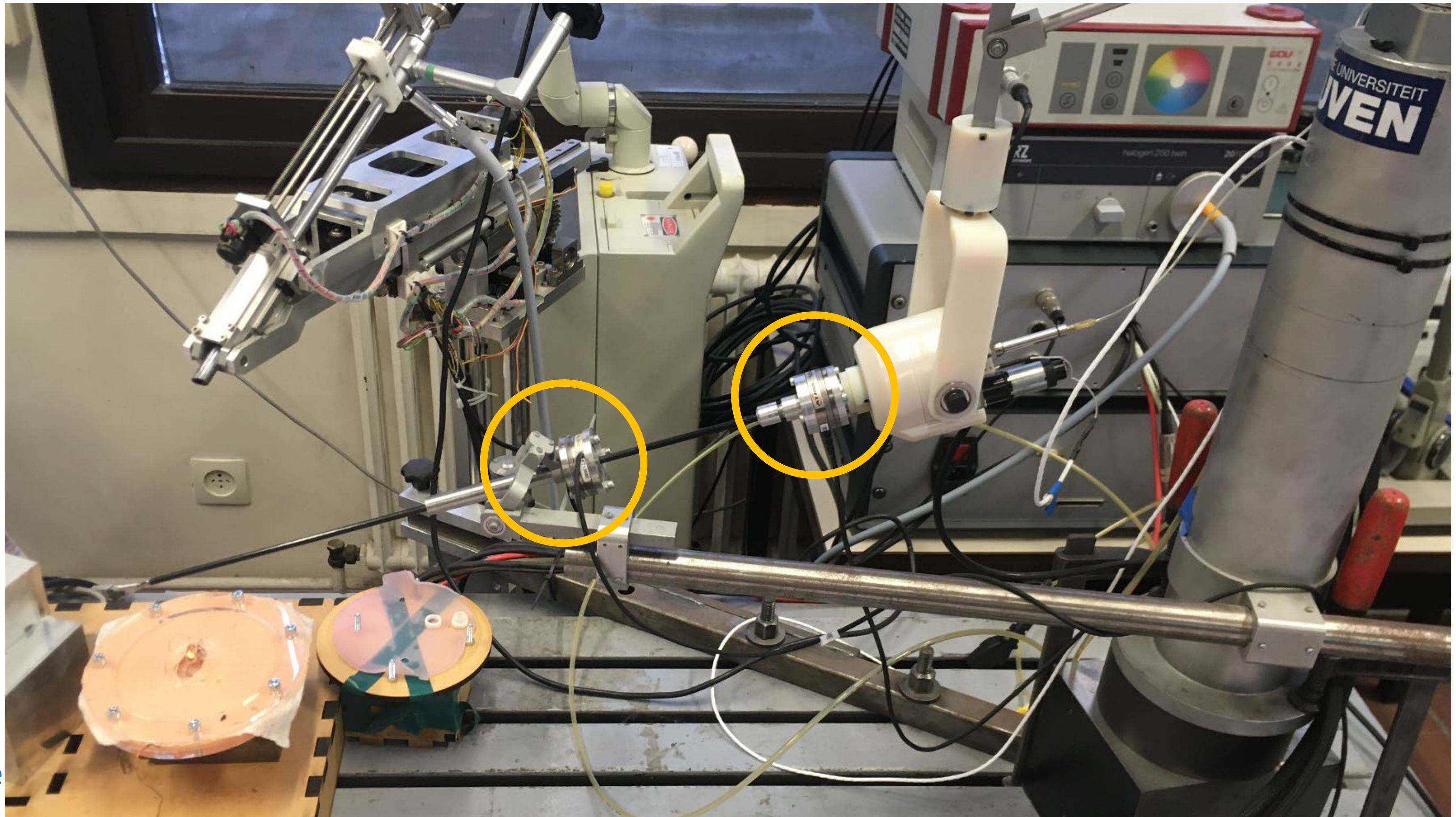


A DLR instrument equipped with a six-axis force-torque sensor

Case study of UI in RMIS: da Vinci

Description and discussion of a UI

- Solution 3: Double force sensor: One sensor in trocar, one between tool and robot
- Problem:
  - Set-up: force sensor attached to the trocar
  - Increases set-up complexity



4. Case study of task oriented UI: RMIS Fetoscopy

Designing User Interfaces in Surgery

Personal guideline used in all projects with surgeons

1. Establish a common language (between surgeons and engineers)
2. Understand their needs (be sure, make a summary with them)
3. Understand the surgery (not become a surgery)
4. Describe surgery from engineering point of view (e.g. finite state machine describing surgery with multilayered approach)
5. Co-identify (jointly with surgeons)
    1. Most challenging actions
    2. Most critical actions in terms of patient safety
6. Propose solutions
7. Test, test and test and go back to 6 as many times as required

Example of task-oriented interactive user interface

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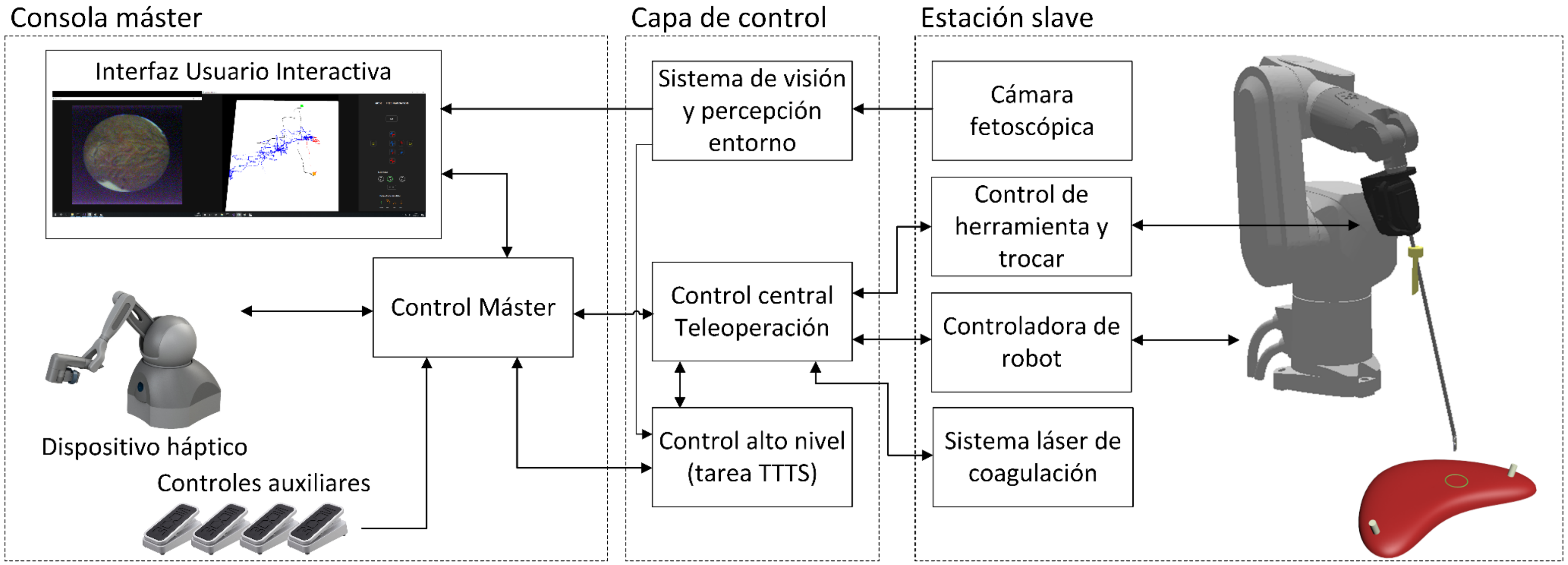
Twin to Twin Transfusion Syndrome teleoperation system

- Multi-modal user interaction
  - Graphical user interface
  - Haptic device guiding fetoscope
  - Pedals for laser actuation and emergency exit



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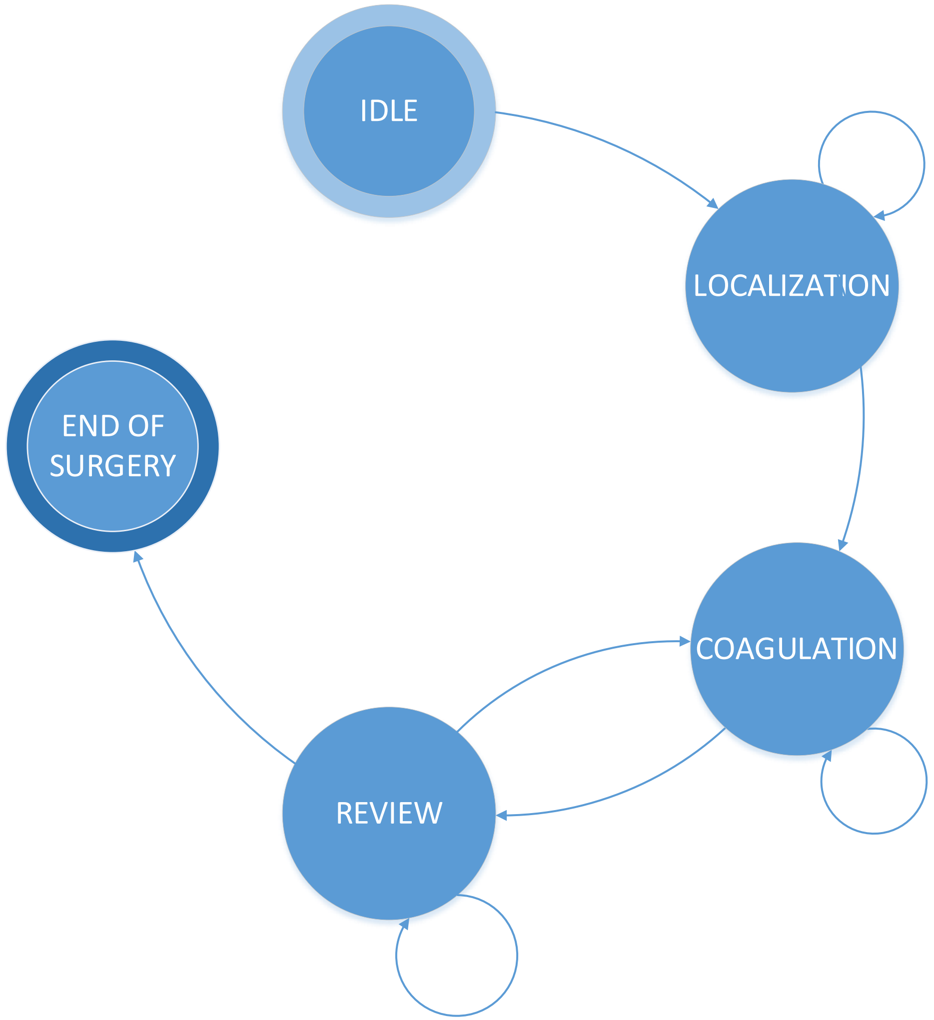
Example of task-oriented interactive user interface

Twin to Twin Transfusion Syndrome

- Task oriented Design UI: Each task shows what required, enables haptic device (input devices) in required mode
- System errors always on UI



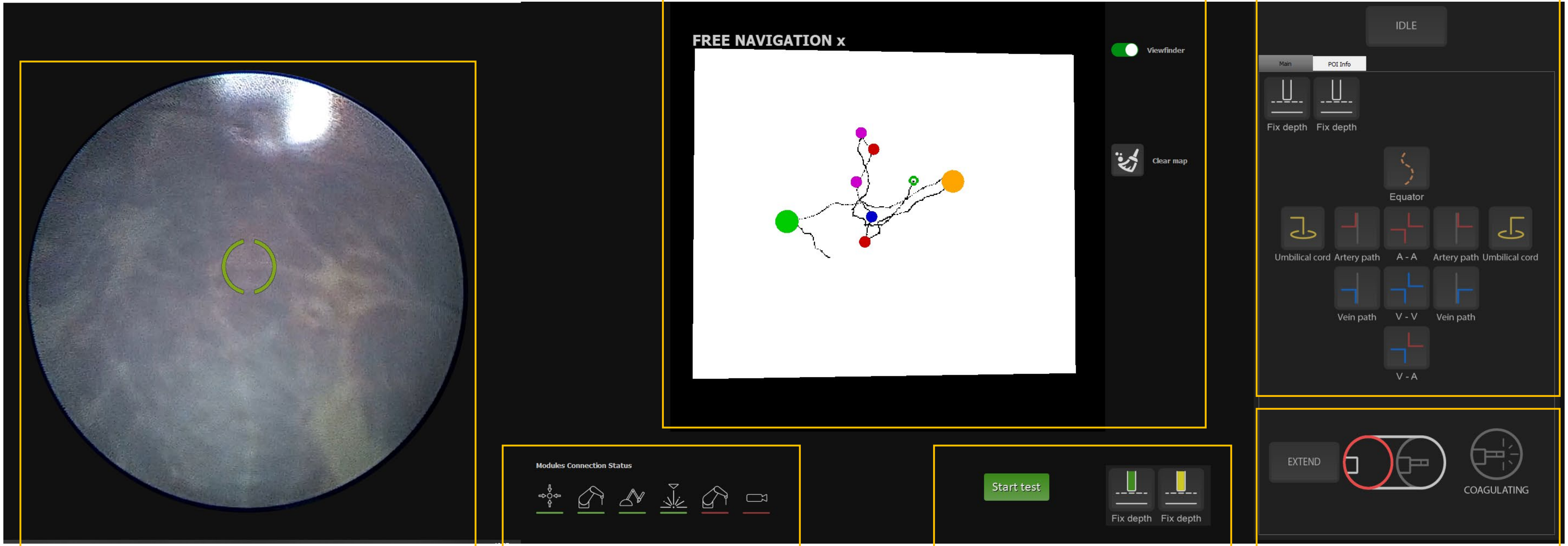
Example of task-oriented interactive user interface

Twin to Twin Transfusion Syndrome

- Task: **Anastomosis Localization**

Placenta navigation map

Map Labelling



Fetoscopic vision + AR

Modules status

Safety Navigation

Coagulation system

Best practices in programming

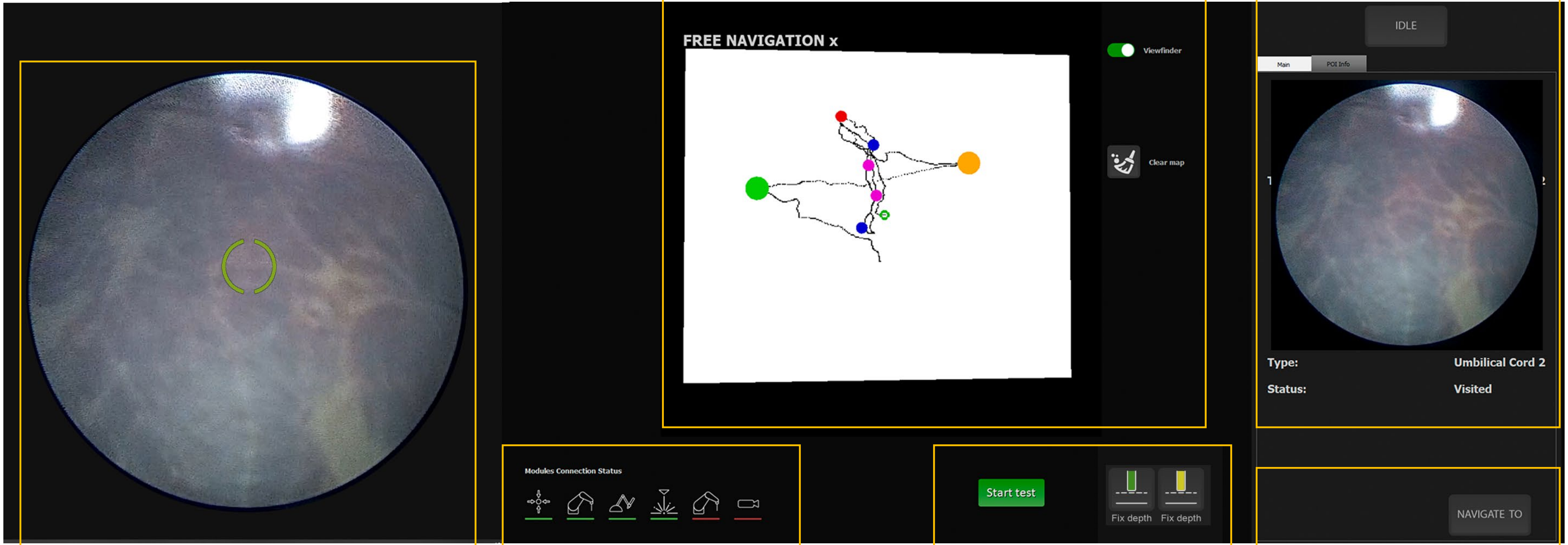
Example of task-oriented interactive user interface

Twin to Twin Transfusion Syndrome

- Task: **Anastomosis Review**

Interactive navigation map

POI Info



Fetoscopic vision + AR

Modules status

Safety Navigation

Navigate to POI

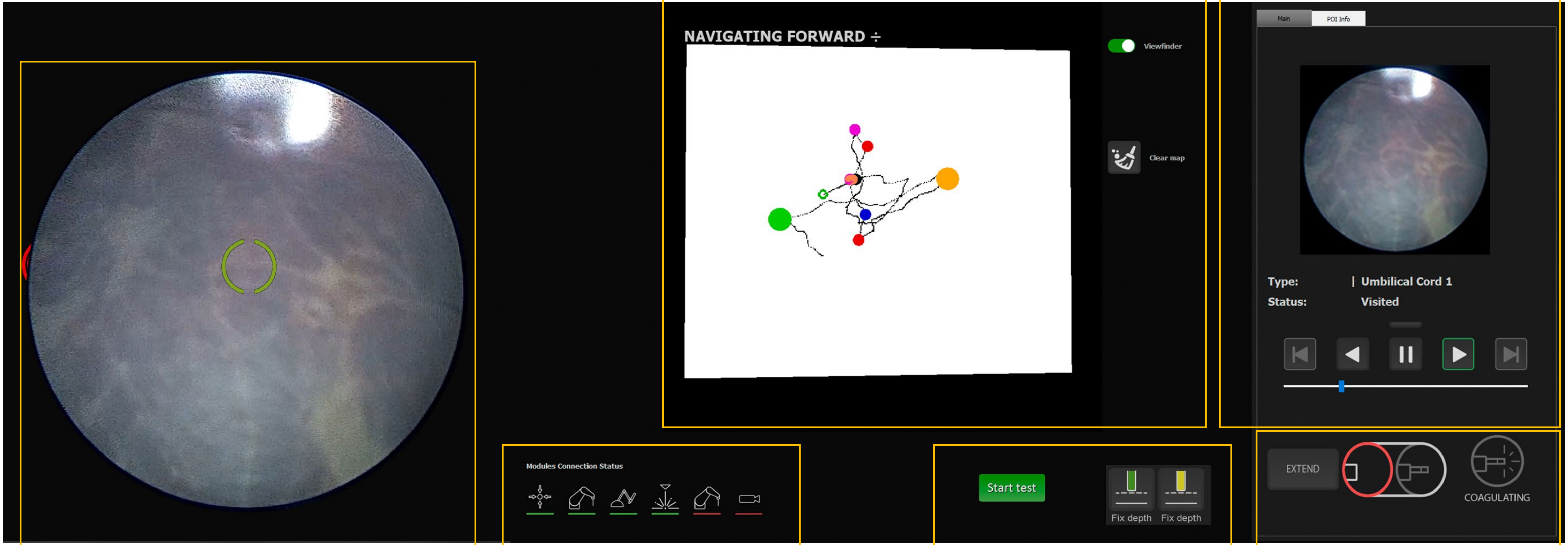
Example of task-oriented interactive user interface

Twin to Twin Transfusion Syndrome

- Task: **Anastomosis coagulation**

Interactive navigation map

Navigation between POIs



Fetoscopic vision + AR

Modules status

Safety Navigation

Coagulation

Best practices in programming

5. Human Robot interaction: Co-manipulation & Teleoperation

Robot guidance methodology

Co-manipulation direct physical interaction with the robot. Robot needs to "feel" the user contact

Teleoperation (or remote operation) indicates operation of a system or robot at a distance by a teleoperator

Control schemas

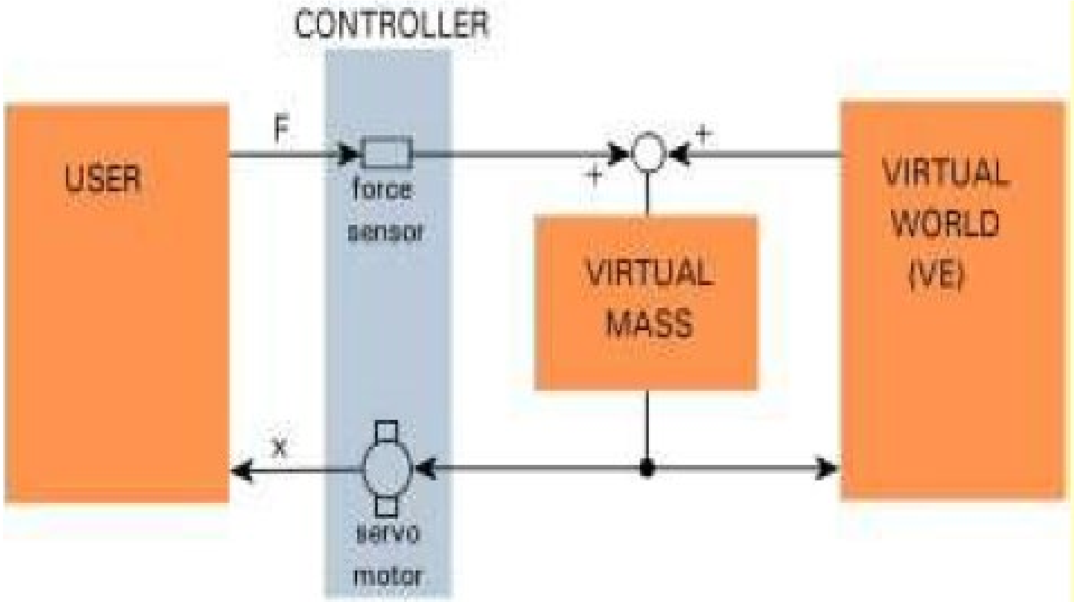
Most typical control approaches

Admittance control: controls motion after a force is measured

Impedance control: controls force after motion or deviation from a set point is measured

Control schemas: Admittance

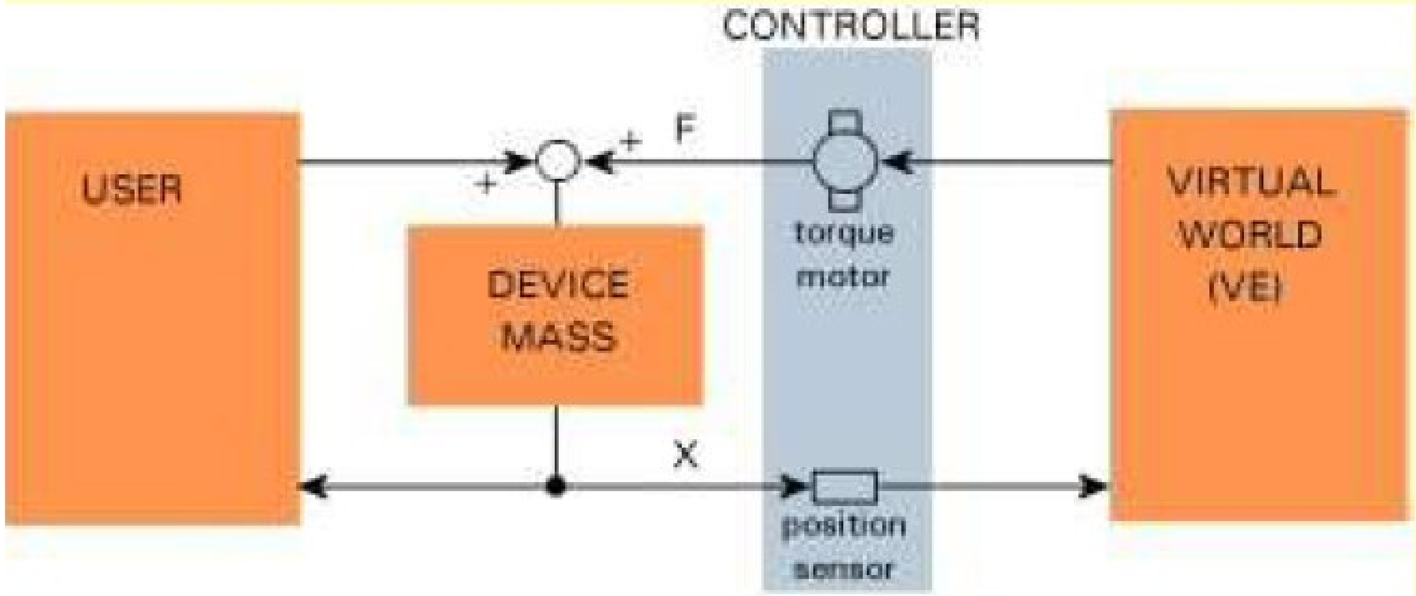
- Example: Co-manipulation, where user interacts with a force sensor, the measured force generates displacement/velocity
- The device measures the forces that the user exerts on it, and reacts with a movement (position, speed, acceleration)
  - Device movement is controlled
  - The device acts as an admittance and the operator as an impedance
  - An admittance robot is one of high inertia and friction (industrial robot)
  - They are considered "sources of speed”



Control schemas: Impedance

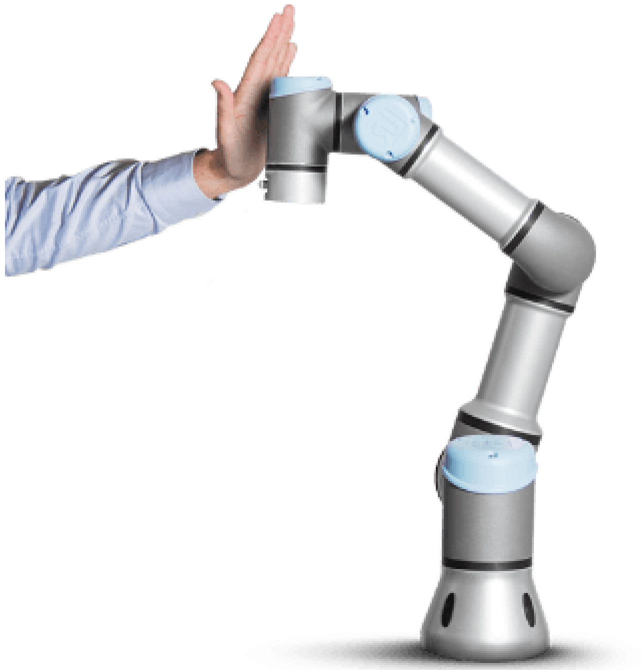
- Example: Teleoperation using a haptic device (low inertia, low friction)

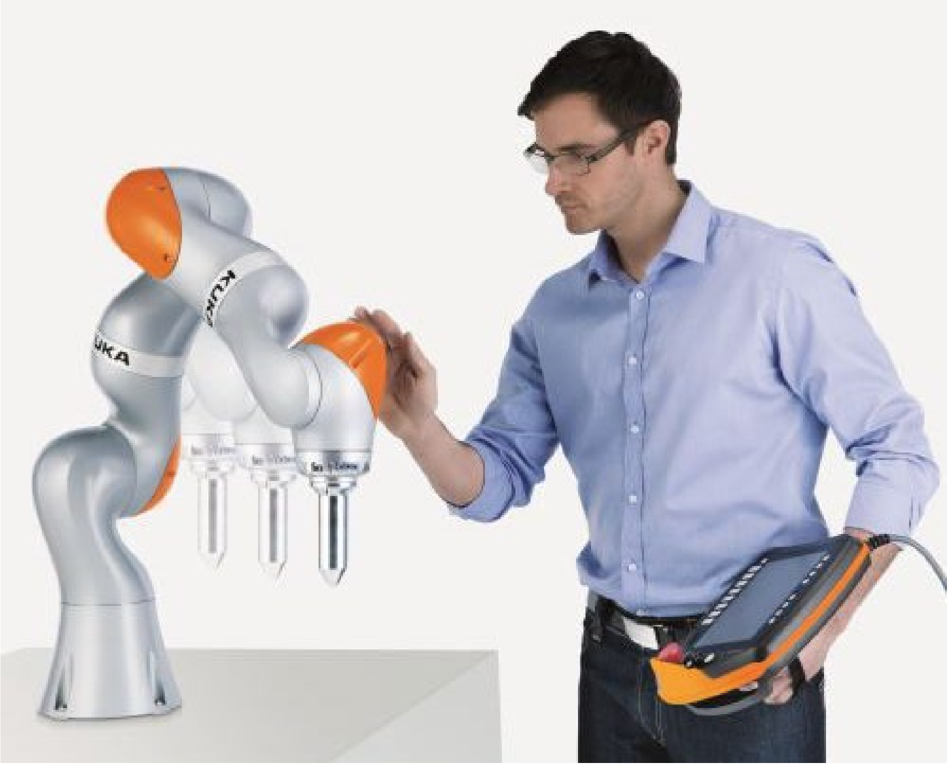
- The user moves the device, which reacts with a force.
- The force of interaction of the device with the operator.
- The device acts as an impedance and the operator as Admittance
- An impedance robot is one of low inertia and friction (the most haptic devices). They are considered “sources of strength. "



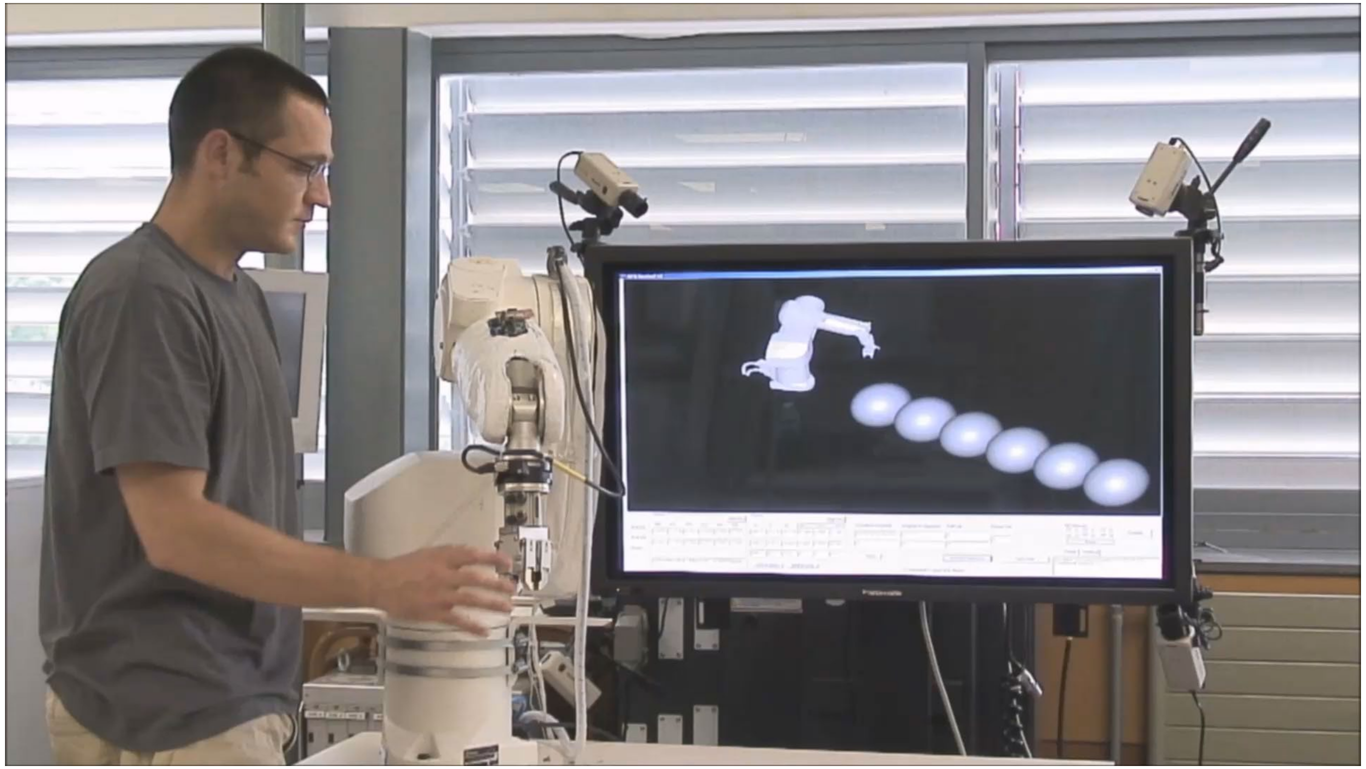
Co-manipulation

- Human users interact directly with the robot
- How: Sensing interaction forces and torques between robots and humans
- Currently, there is a new field in robotics named: cobots (collaborative robots)
  - Cobots are designed to work jointly with humans
  - Cobots are equipped with force/torque sensors at each joint to detect contacts





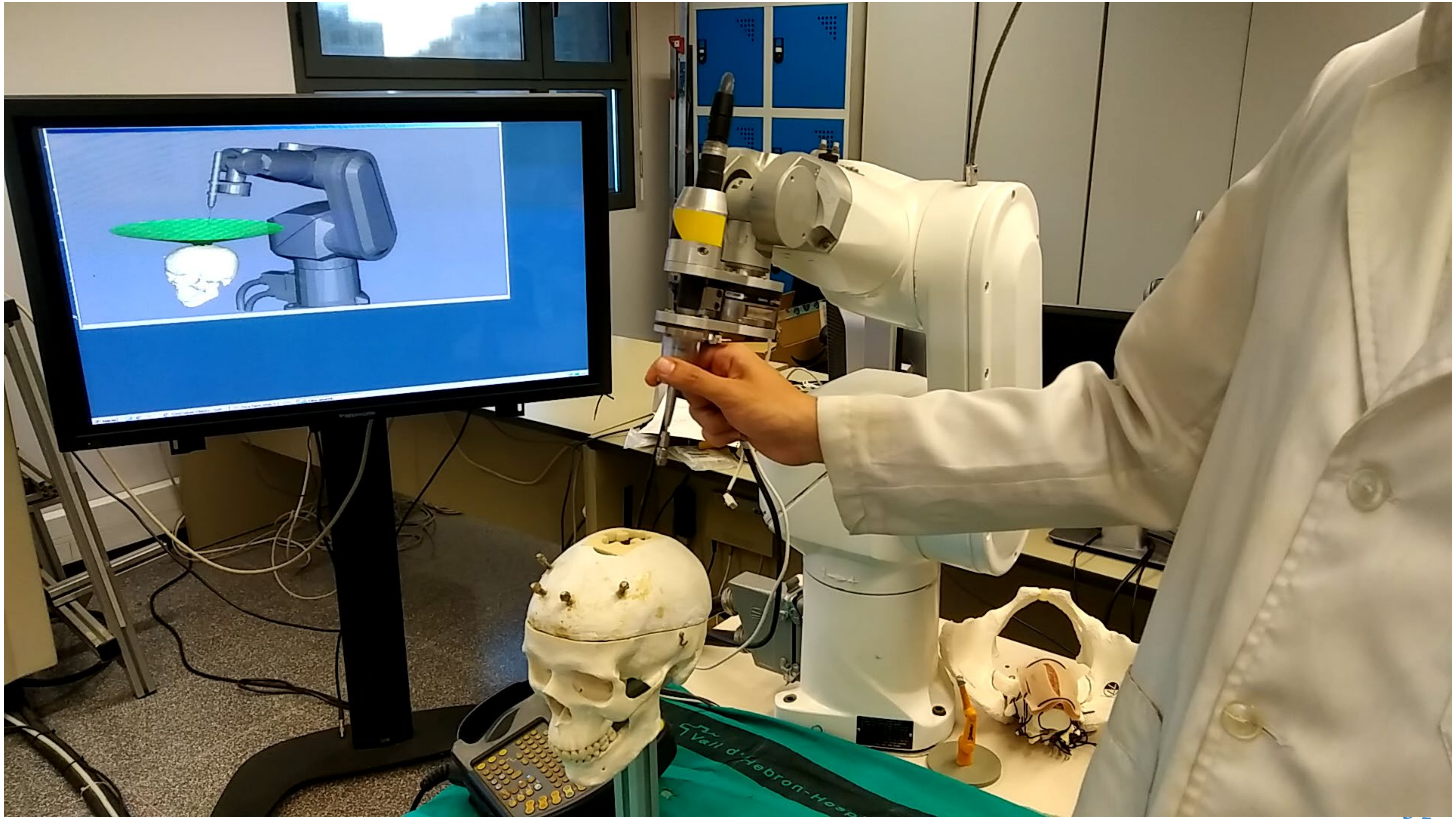
Co-manipulation



$$XR = f(F,T)$$

Function opened to be designed as required.
Not necessary to follow real physics

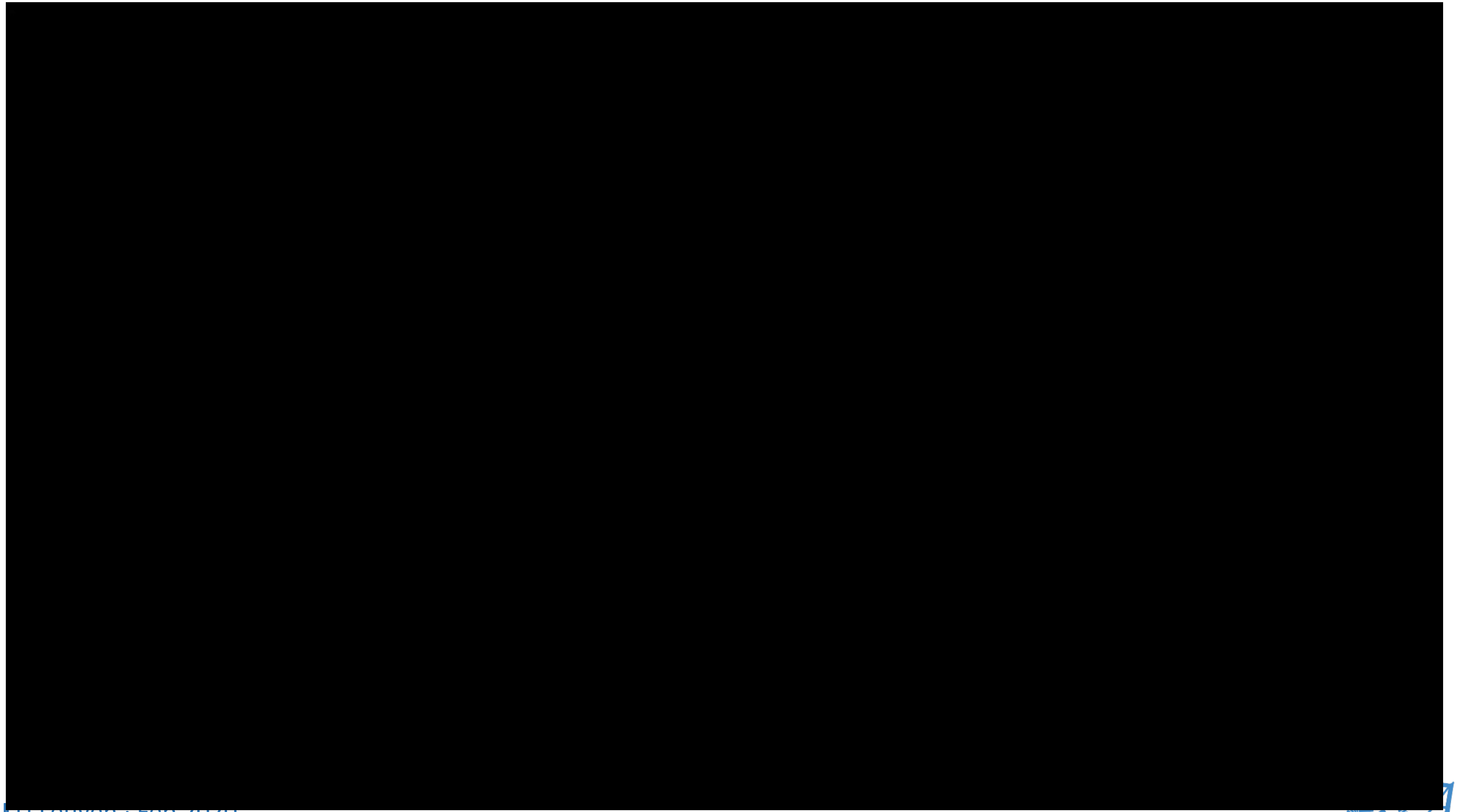
Co-manipulation



Human Robot interaction: Co-manipulation & Teleoperation

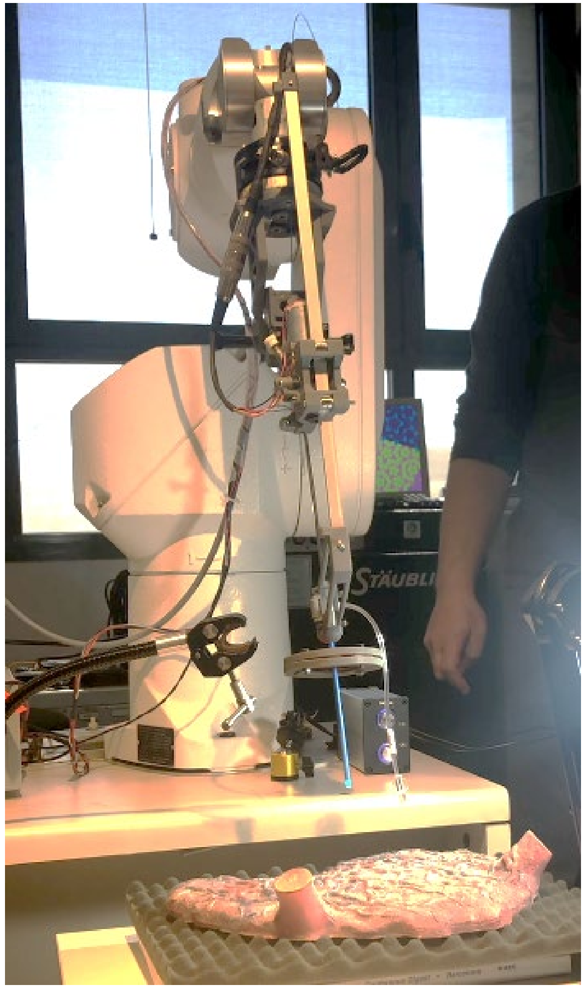
Teleoperation

Example provided by BBZ (spin-off from UniVr)



Mixed system: Co-manipulation & Teleoperation

- Depending on the task, use a different interaction control schema
- Example of Fetoscopy RMIS co/tele system
  - Co-manipulation
    - Set-up process: guide the robot to insertion point
    - Define pivoting point of the fetoscope
    - Fetoscope final extraction and remove setup
  - Teleoperation
    - Regular Human-Robot interaction method during surgery



6. Virtual Fixtures and Haptic feedback

Definition

- Active constraints, also known as **virtual fixtures**, are high-level control algorithms which can be used to assist a human in man–machine collaborative manipulation tasks. (1)
- The active constraint controller monitors the robotic manipulator with respect to the environment and task (1)
- (typically) Used to either guide the user along a task-specific pathway or limit the user to within a “safe” region (1)
- VF are used to improve certain aspects of the operator's skills (e.g. accuracy, completion time, etc.) or to protect certain regions of the workspace (forbidden regions, tool guidance, etc.)

(1): S. A. Bowyer, B. L. Davies and F. Rodriguez y Baena, "Active Constraints/Virtual Fixtures: A Survey," in IEEE Transactions on Robotics, vol. 30, no. 1, pp. 138-157, Feb. 2014.

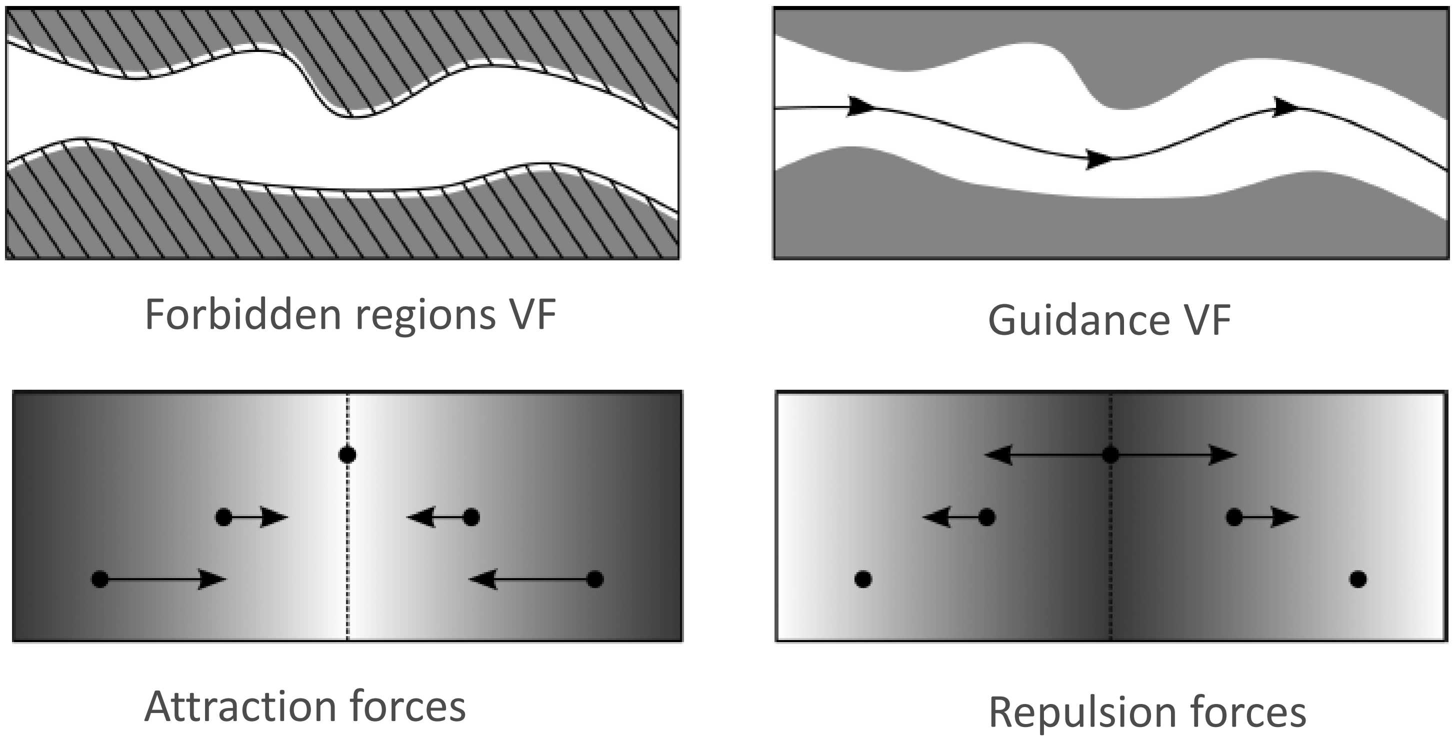
Types of Virtual Fixtures

- One classification: assisted guidance and forbidden region.
  - **Guidance VF** are designed to help the operator to guide the robot along a preferred path. For instance, a force attraction, in the form of a mass-spring-damper between the robot's Tool Center Point, TCP, and the path to be followed, minimizes undesired trajectory deviations.
  - **Forbidden regions VF** keep the robot out of certain regions of the workspace. For instance, a repulsion force like a virtual wall, can be generated when the robot TCP reaches the limit of a forbidden region.

(1): S. A. Bowyer, B. L. Davies and F. Rodriguez y Baena, "Active Constraints/Virtual Fixtures: A Survey," in IEEE Transactions on Robotics, vol. 30, no. 1, pp. 138-157, Feb. 2014.

Types of Virtual Fixtures

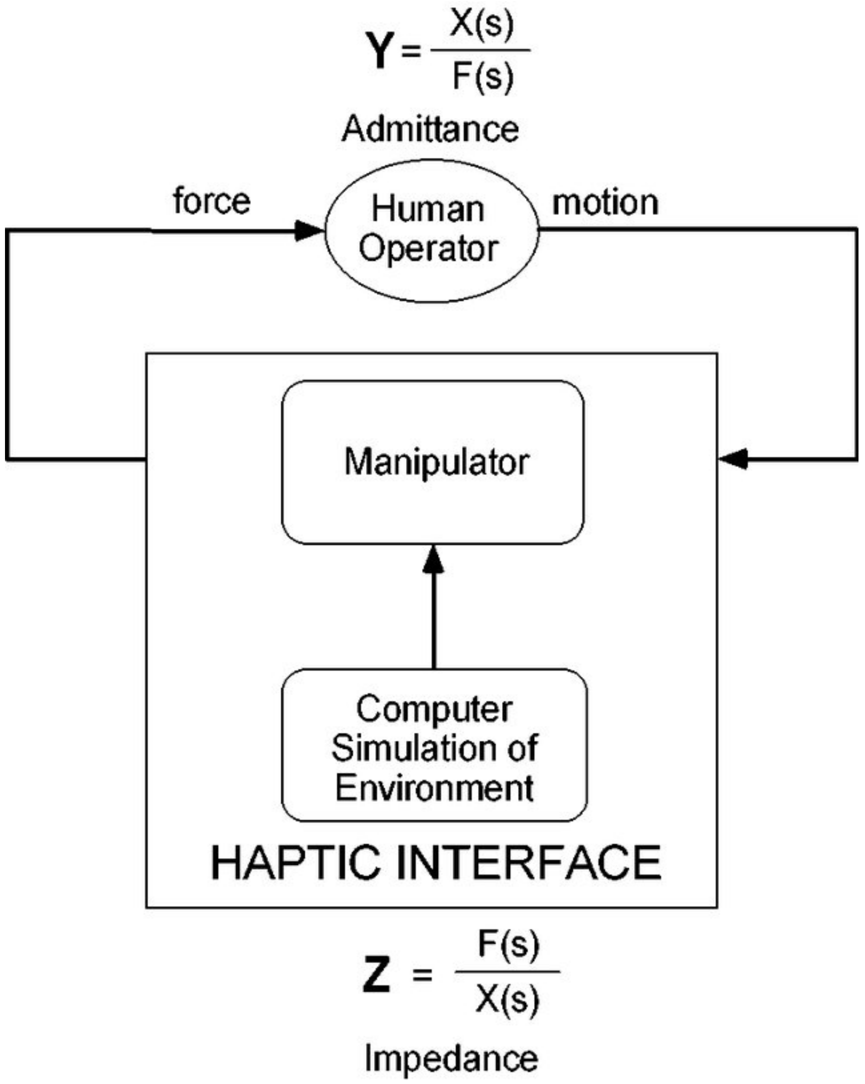
Relative position VF: F = f(x,k)

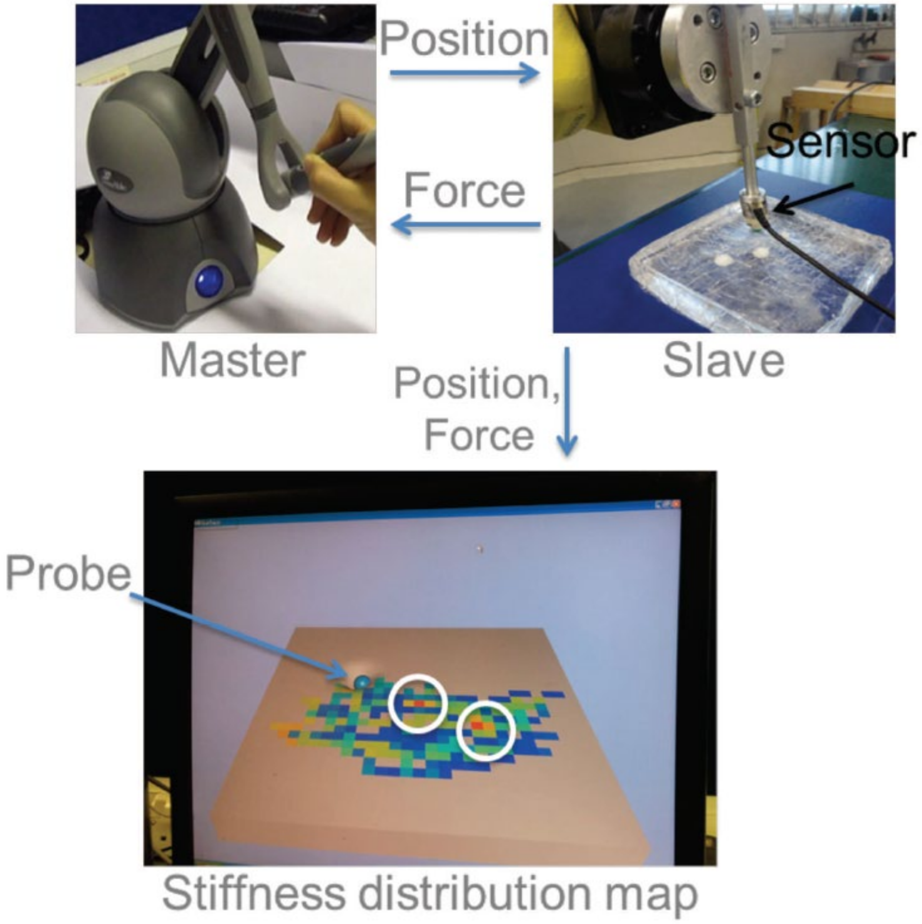


Relative velocity VF: F = f(x',k) (Viscous media to control velocity)

(1): S. A. Bowyer, B. L. Davies and F. Rodriguez y Baena, "Active Constraints/Virtual Fixtures: A Survey," in IEEE Transactions on Robotics, vol. 30, no. 1, pp. 138-157, Feb. 2014.

Haptic feedback schema

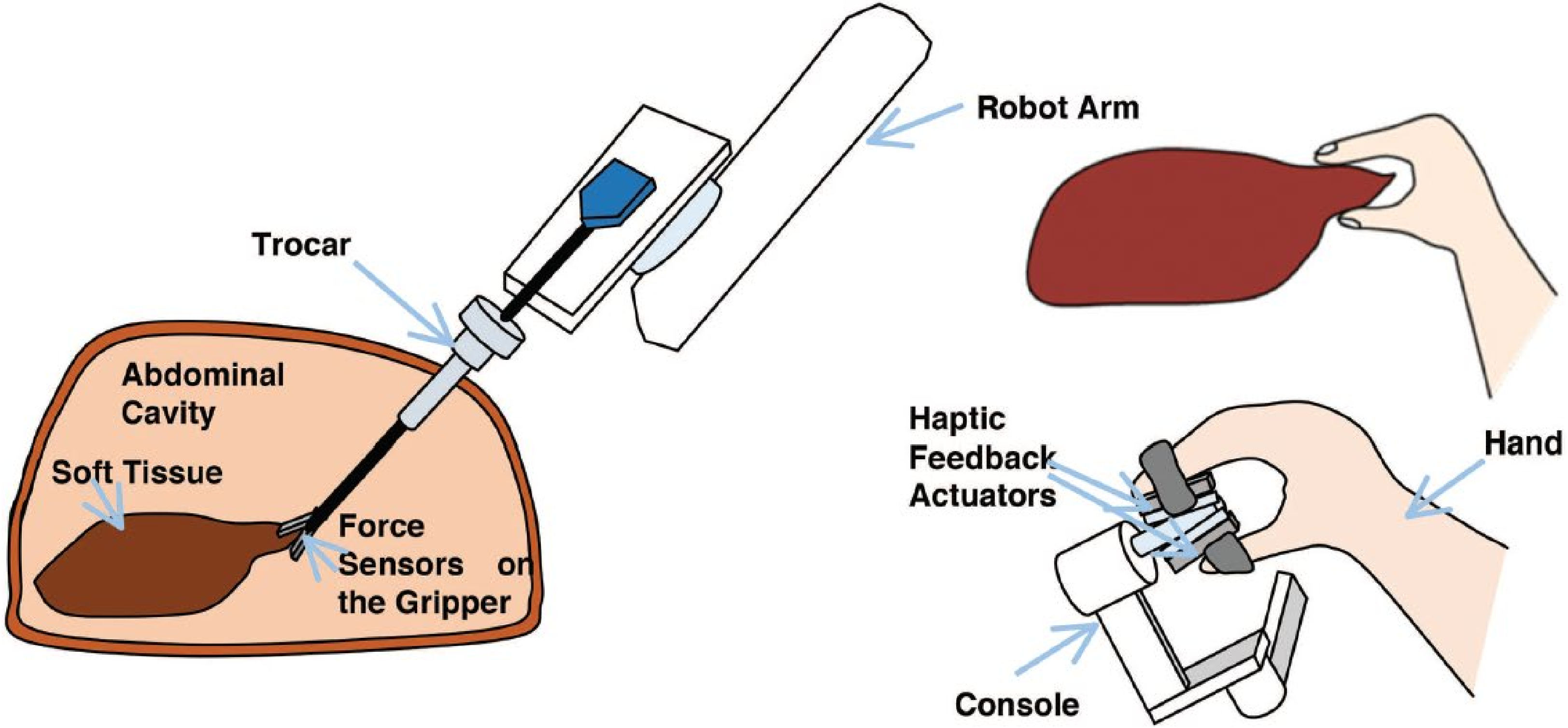




Haptic feedback schema

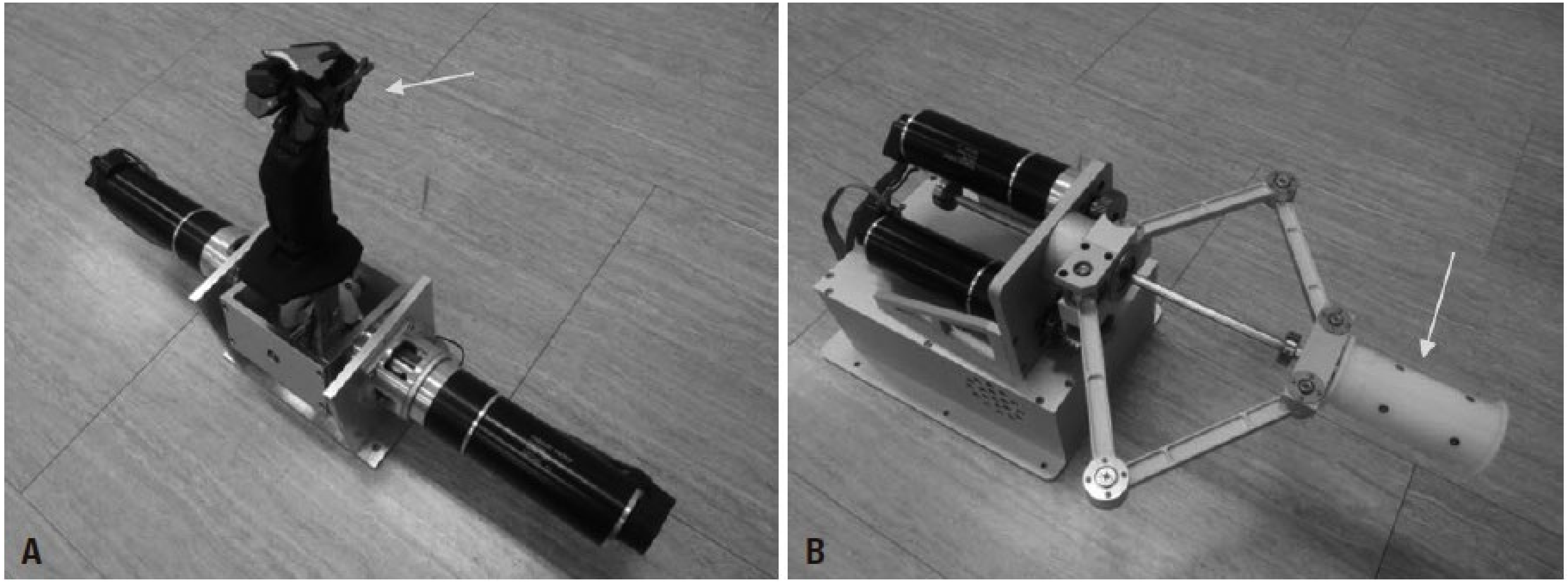
Schema of double haptic feedback

1. User defines tool tip pose, receives contact forces between tool and organ
2. User defines gripper position, receives grasping forces between gripper and organ



Haptics in colonoscopy

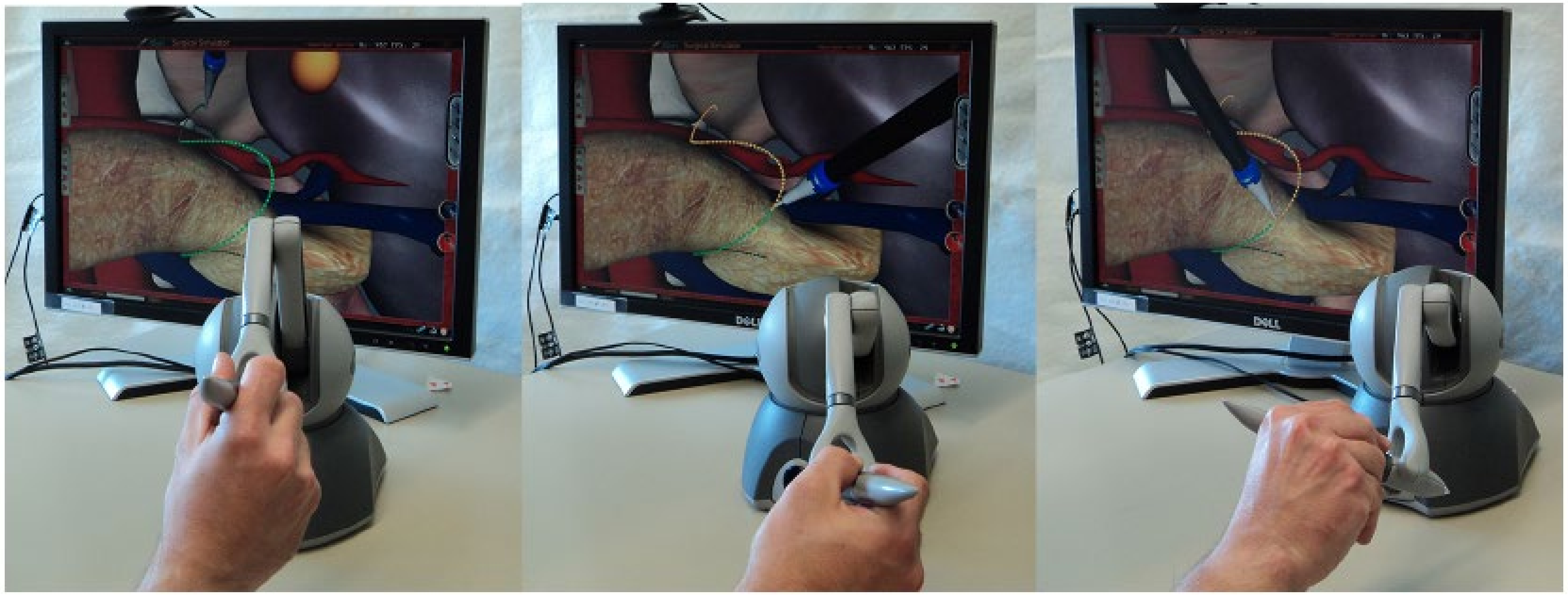
(A) Tilting device for controlling up-down and right-left angulation of endoscopic tip.
(B) Insertion and rotation device for controlling insertion, retraction, and rotation of endoscope.



Sheth Kunj R., Koh Chester J. "The Future of Robotic Surgery in Pediatric Urology: Upcoming Technology and Evolution Within the Field" in Frontiers in Pediatrics

Training in laparoscopy

- Goal: aid surgeons to follow a path without collision inside the abdominal region
- Environment: virtual abdomen + phantom haptic device



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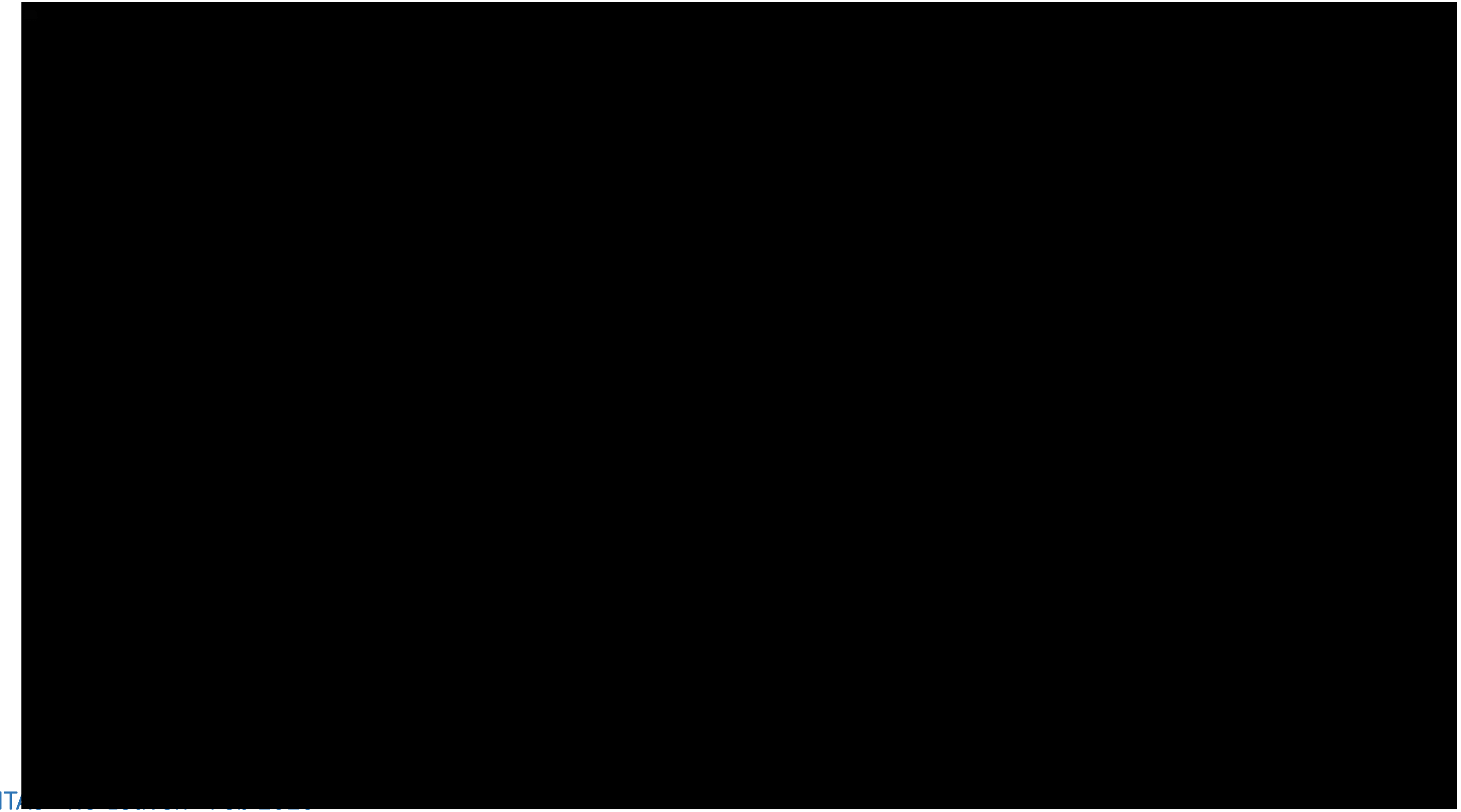
Training in laparoscopy

- Use of several virtual aids in laparoscopic tools navigation training



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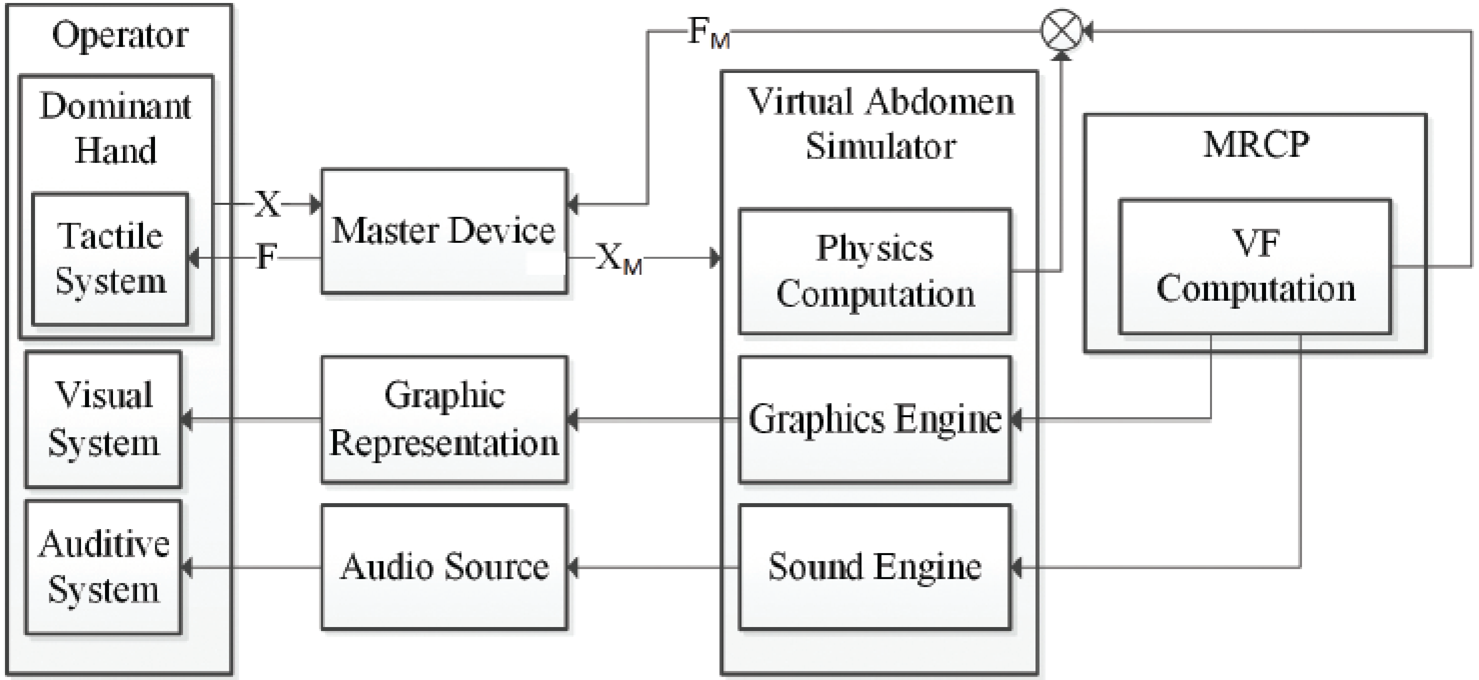
Virtual Fixtures and multi-modal information for training

Training in laparoscopy

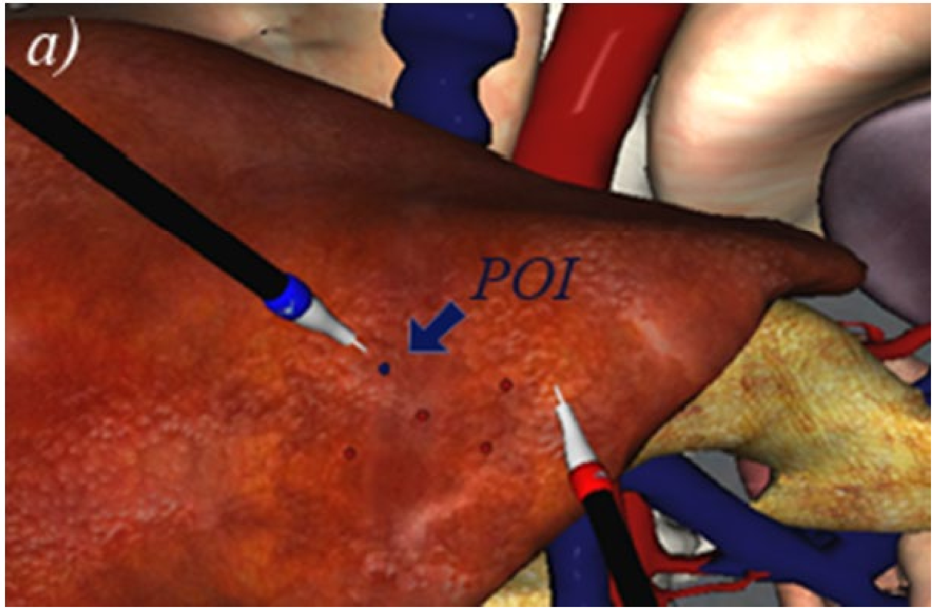
- Control block schema of the simulation haptic system



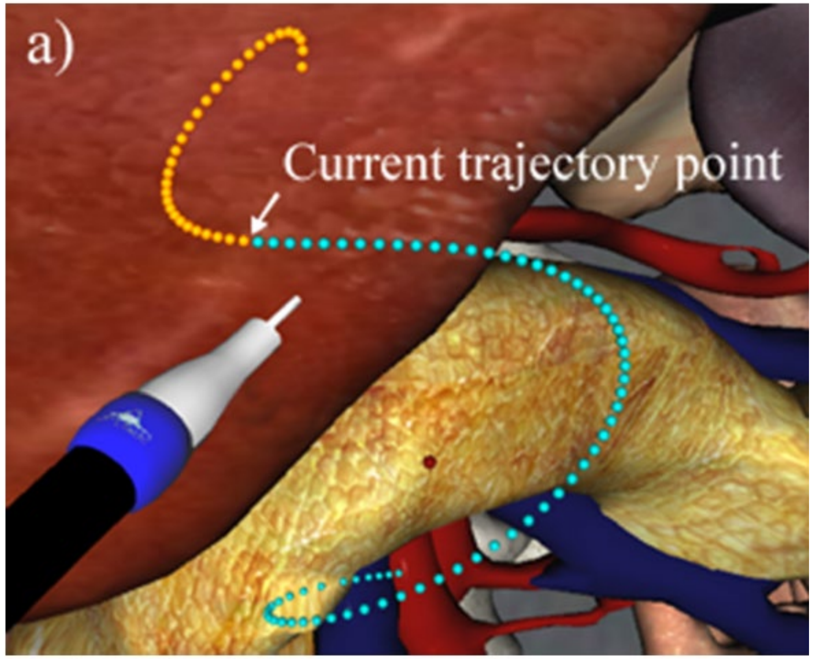
Task oriented virtual fixtures

- Proposal: Combined use of multiple virtual fixtures with different modality to aid in an specific task.

- Task 1: Point targeting



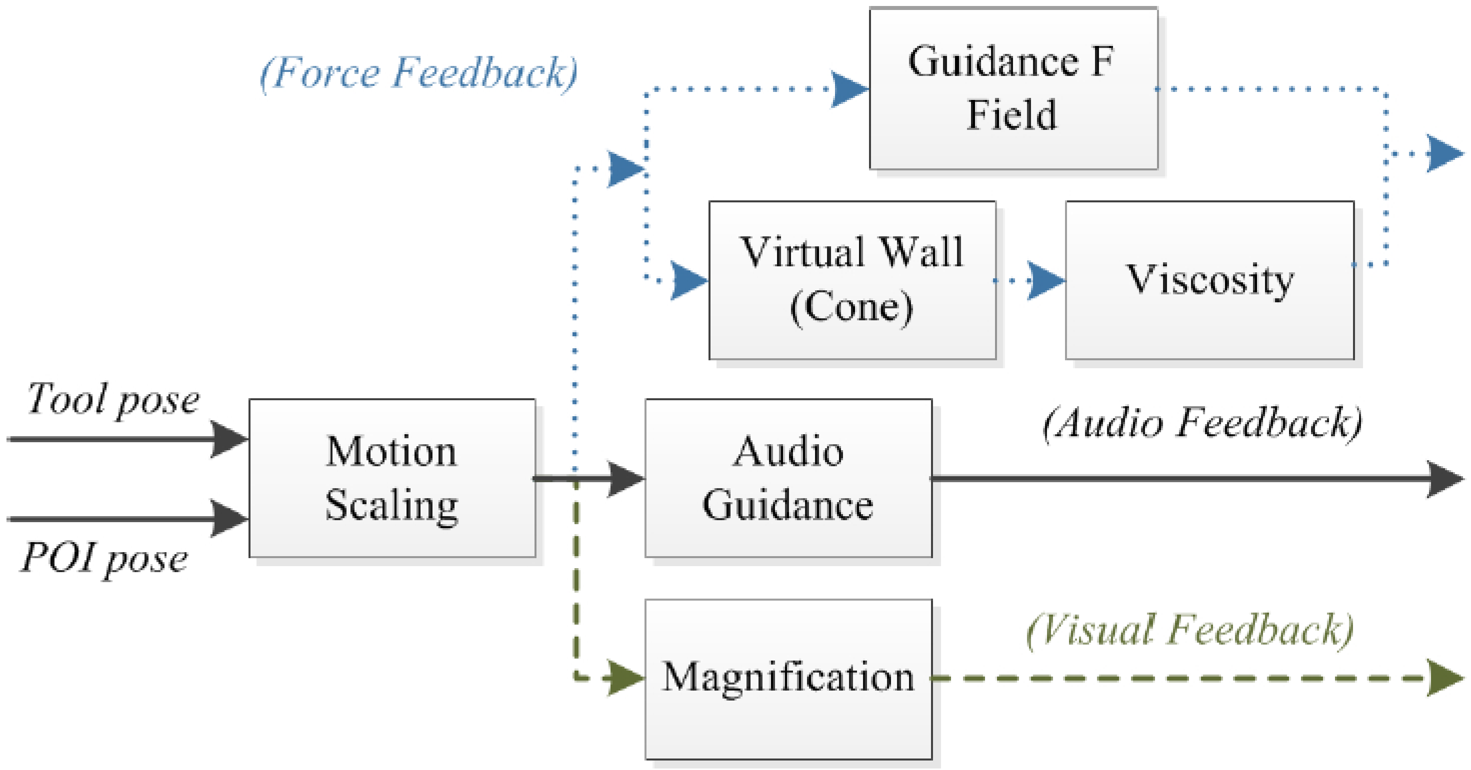
Task 2: Trajectory following



- **Short exercise: propose schema for any or both of the tasks using multi-modal VF (15')**

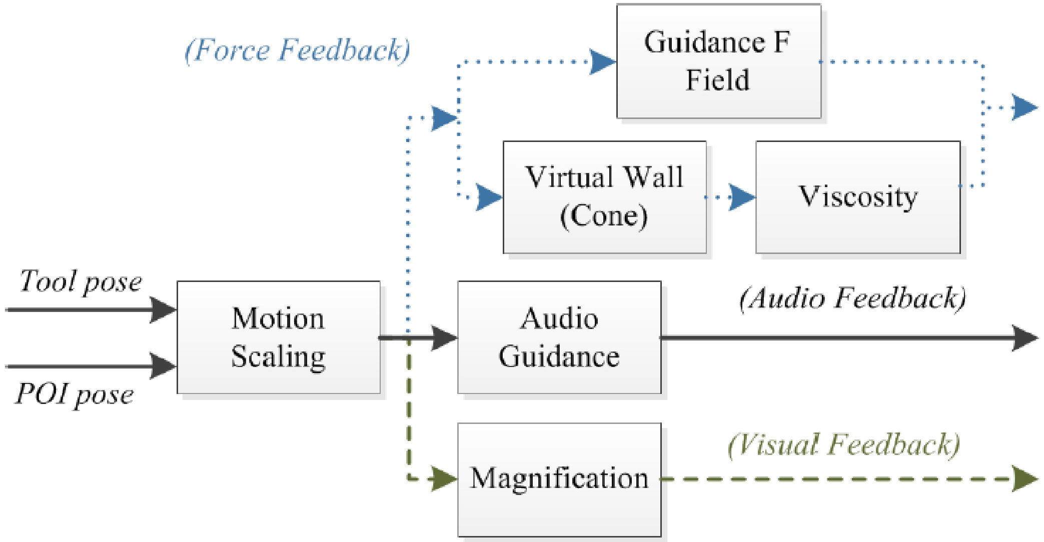
Task oriented virtual fixtures

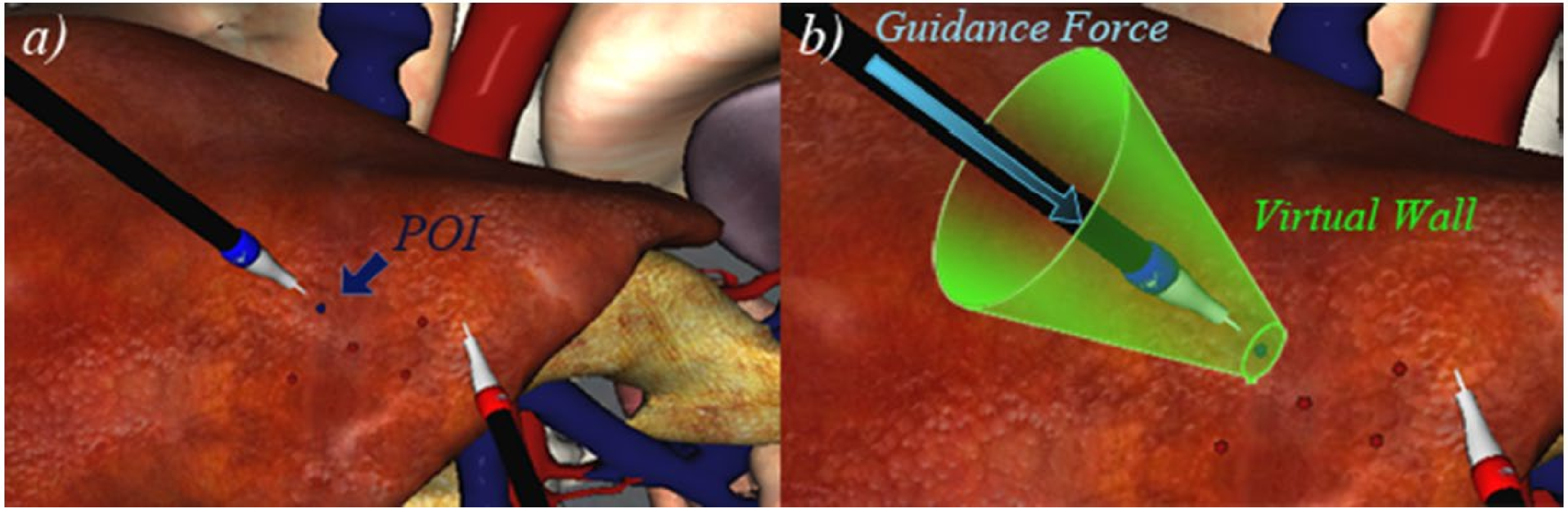
- Task 1: Point targeting



Task oriented virtual fixtures

- Task 1: Point targeting

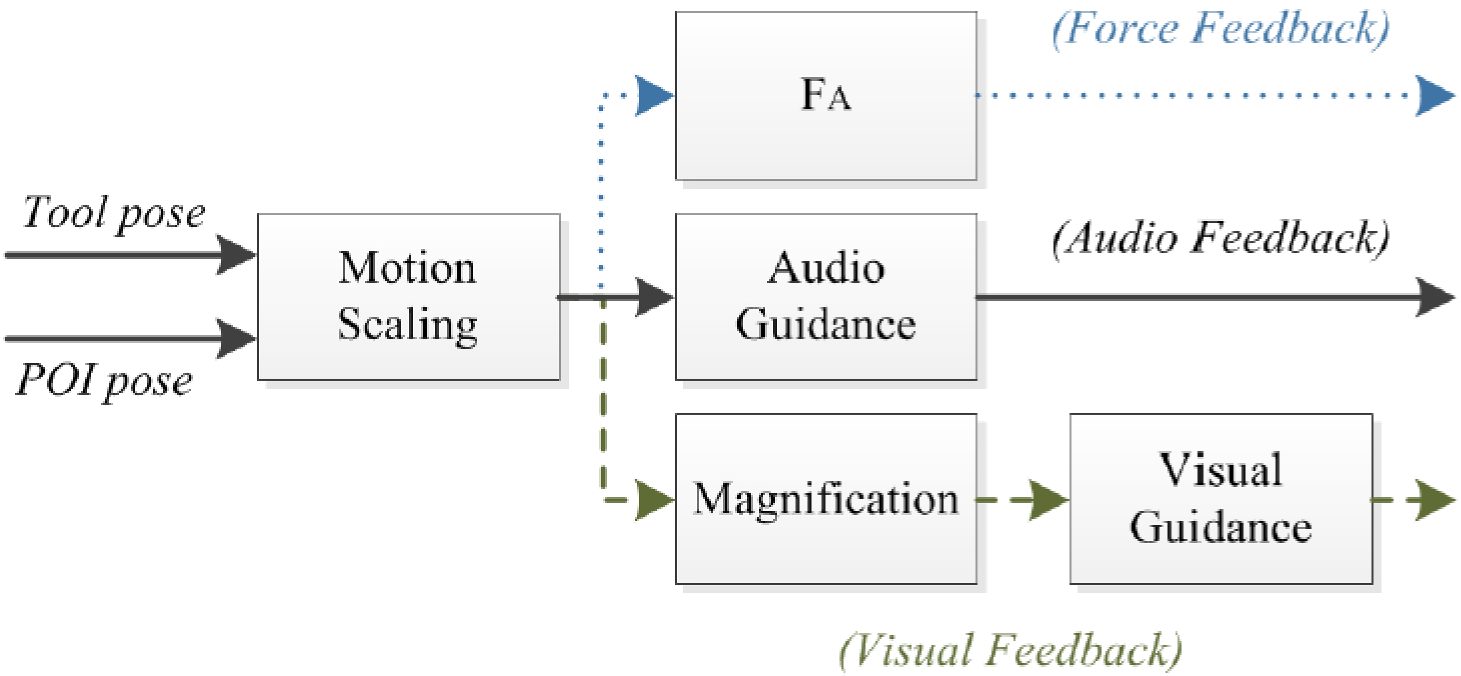




Virtual Fixtures and multi-modal information for training

Task oriented virtual fixtures

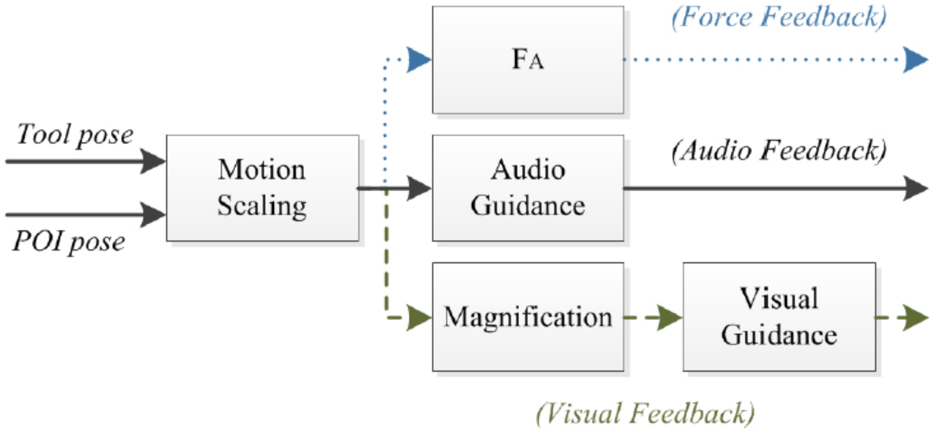
- Task 2: Trajectory following

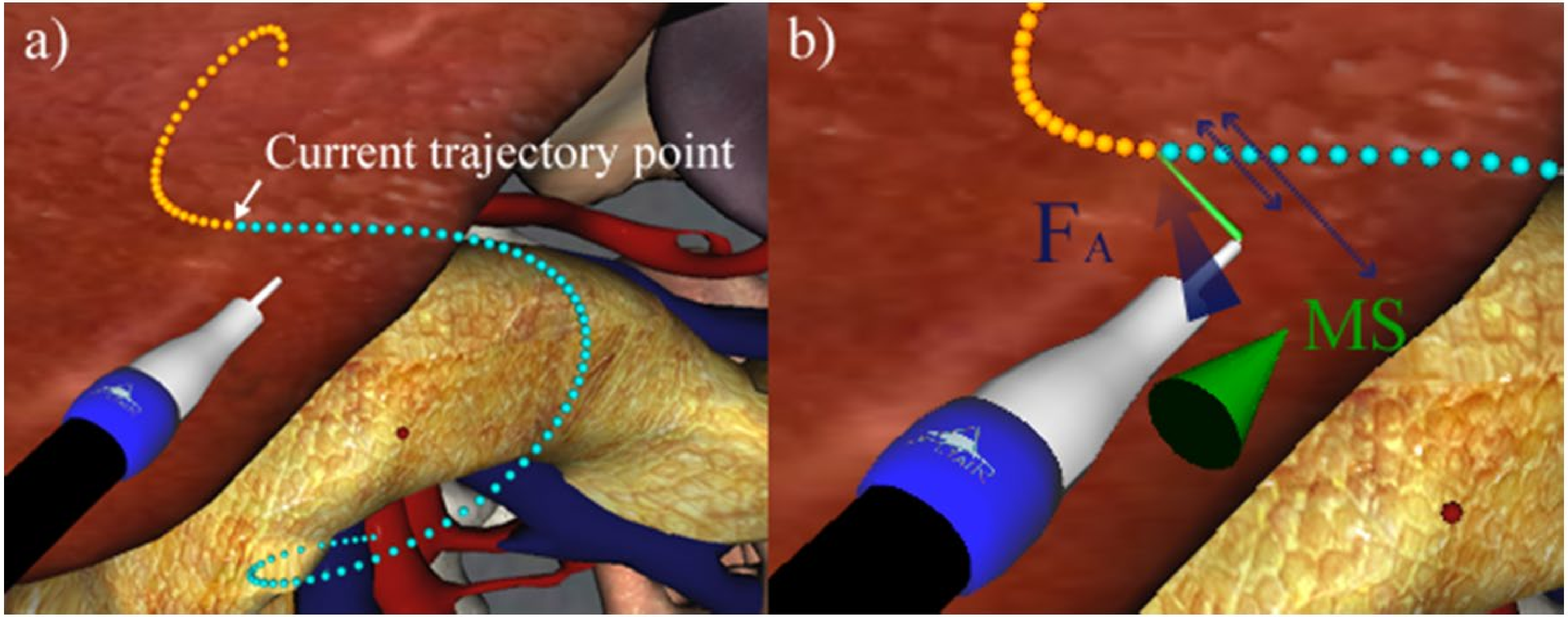


Virtual Fixtures and multi-modal information for training

Task oriented virtual fixtures

- Task 2: Trajectory following



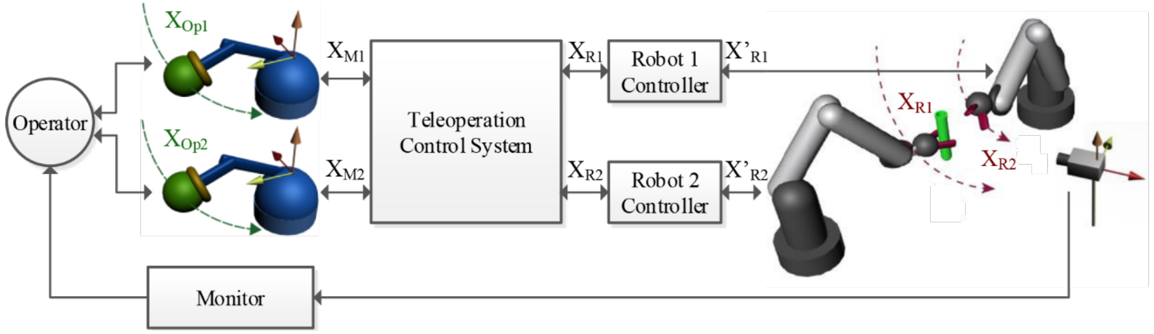


Task oriented teleoperation, change of teleoperation paradigm

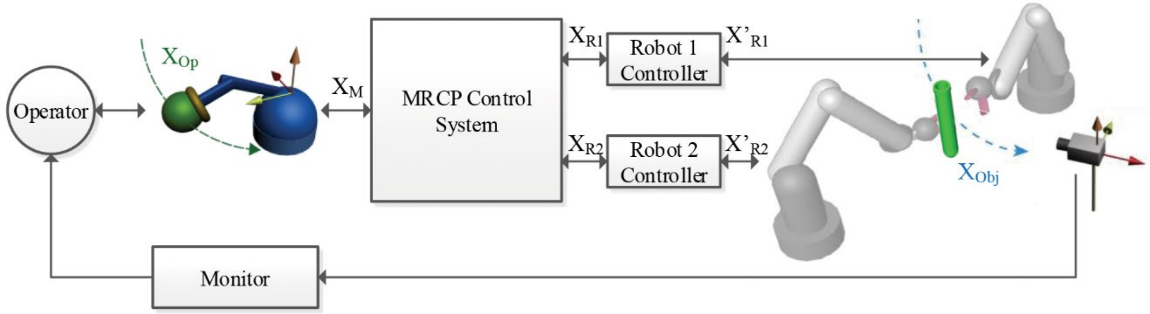
Change of teleoperation paradigm: task-oriented teleoperation

- User teleoperates the task, not the robots.
- E.g. Inspection of an object in front of a camera => user guides the object

Standard approach



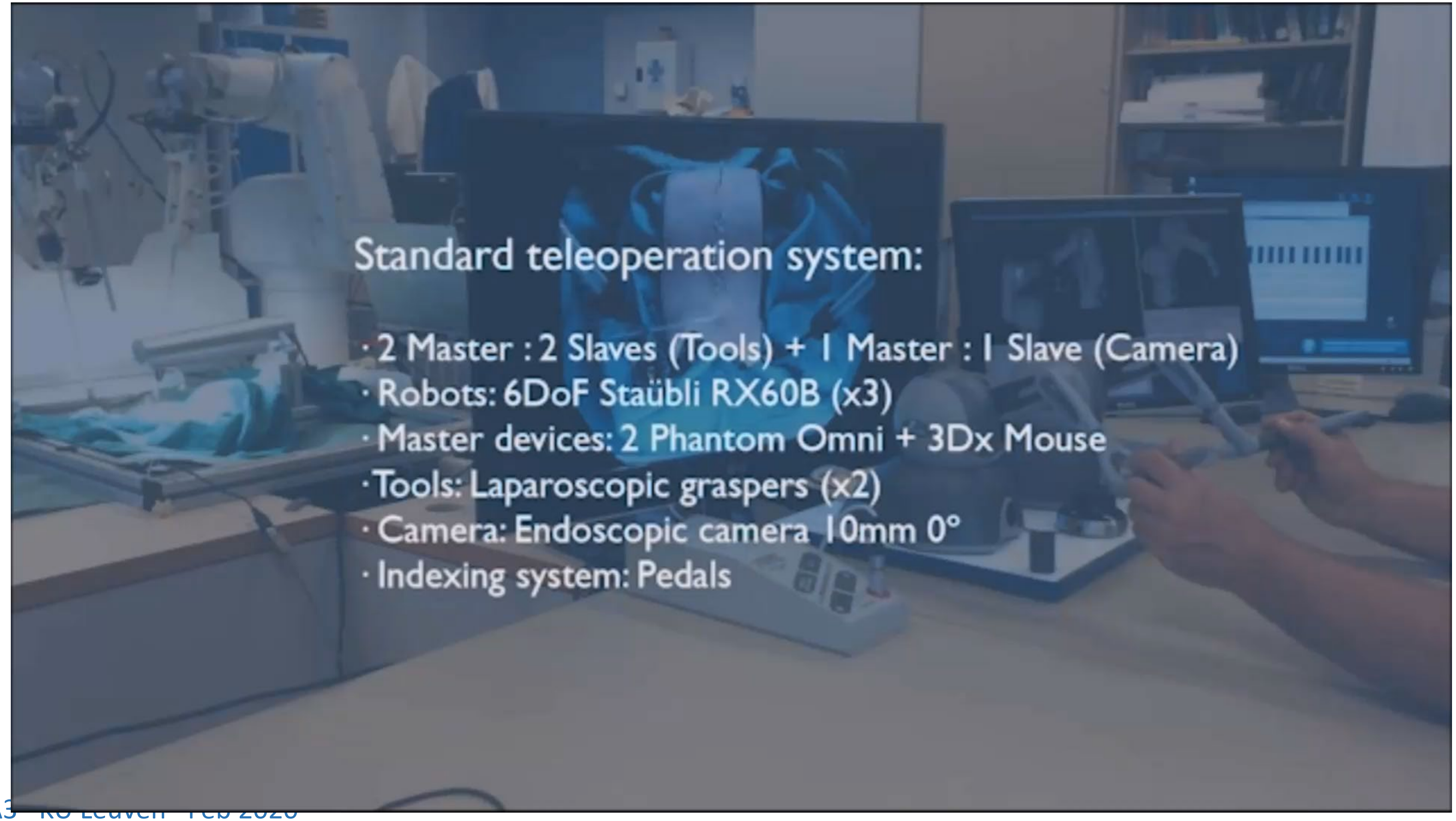
Task-Oriented approach



Task oriented teleoperation, UI + teleoperation control

Task oriented teleoperation, change of teleoperation paradigm

- Example of suture in RMIS
- UI (master) adapted to new teleoperation

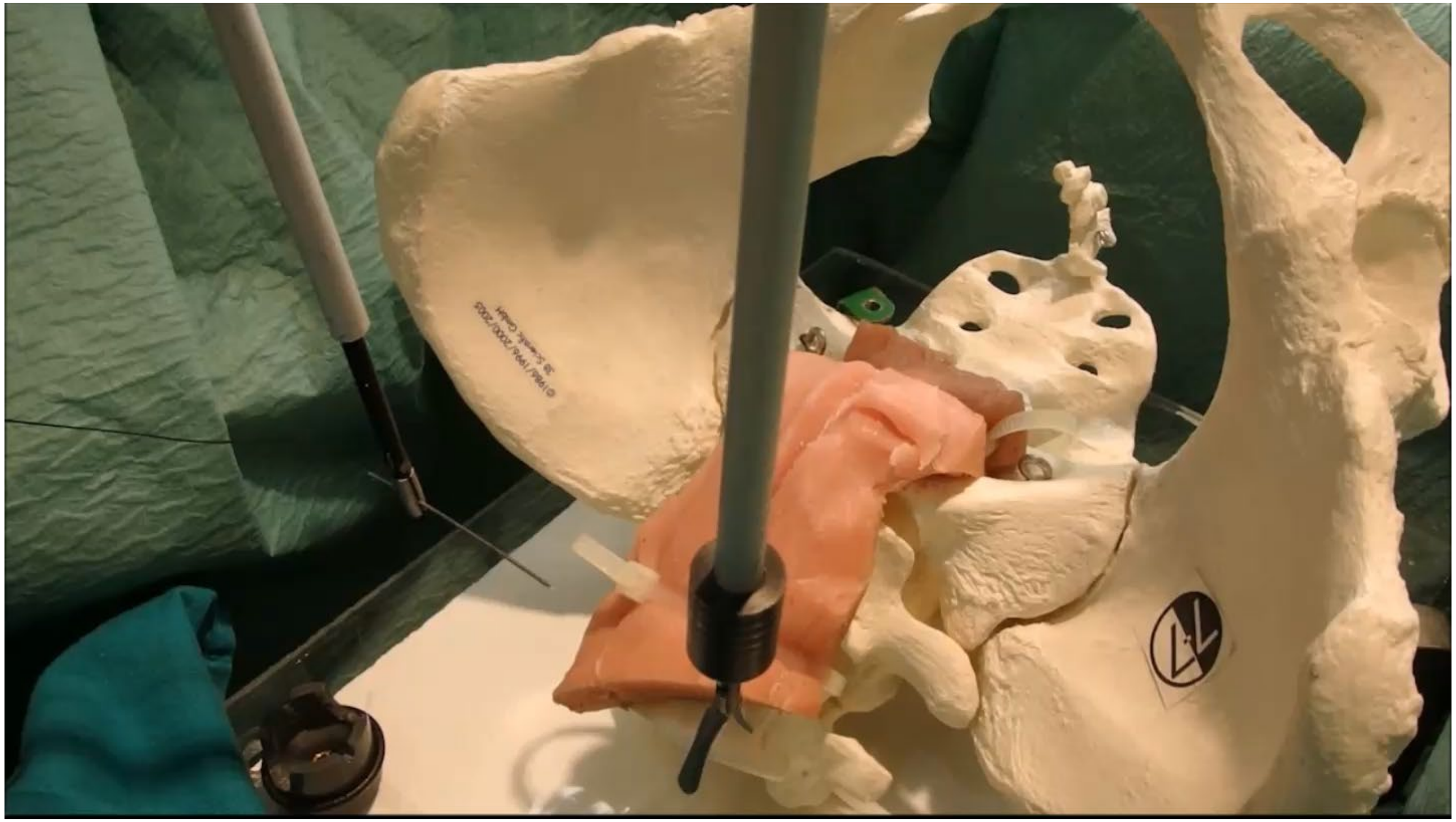


Best practices in programming

Task oriented teleoperation, UI + teleoperation control

Task oriented teleoperation, change of teleoperation paradigm

- Example of suture in RMIS
- UI (master) adapted to new teleoperation

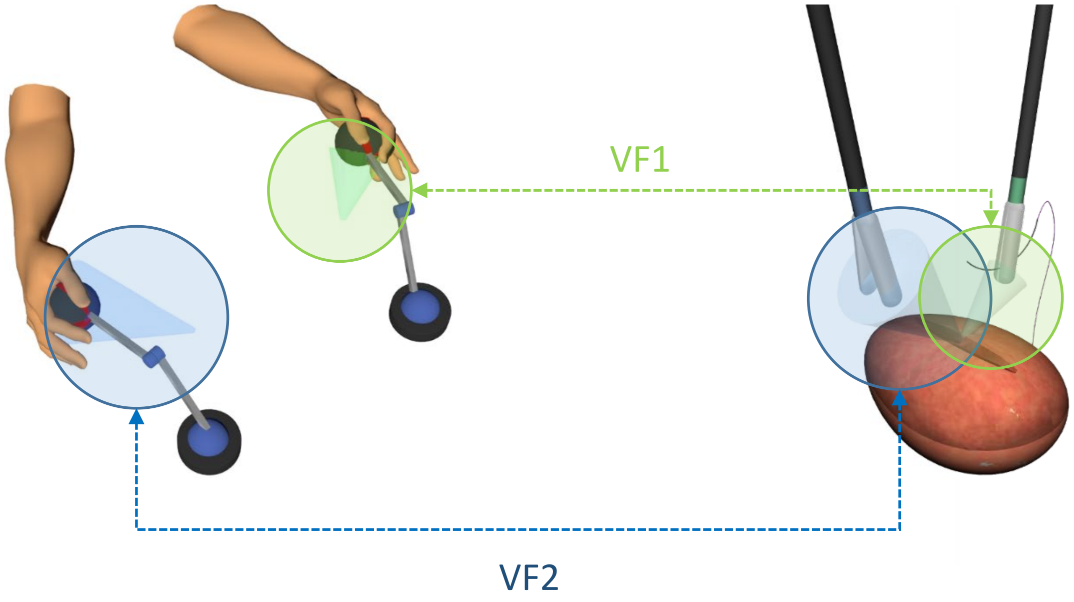


Task oriented teleoperation, Force Feedback

Task oriented teleoperation, change of teleoperation paradigm

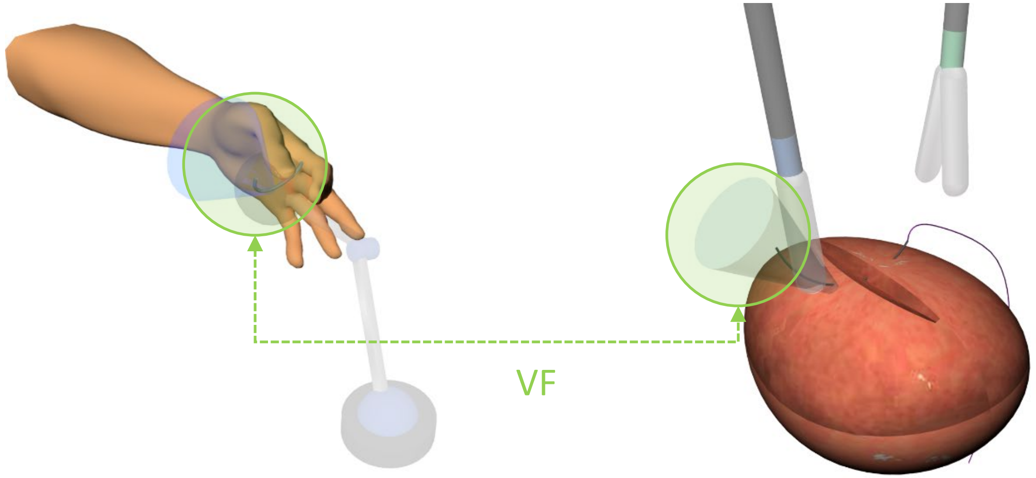
- Teleoperation system: 2M:2S
- VF depends on the distance between tool and ROI

Multiple VF acting at each hand: increase cognitive load, create confusion to operator



Task oriented teleoperation, change of teleoperation paradigm

- Teleoperation system: 1M:2S
- VF depends on the distance between tool and ROI



7. Simulation, Haptics and Augmented Reality in training

Audio Guidance and “ghost” mode for laparoscopy training

Augmented reality in surgery

Colonoscopy training

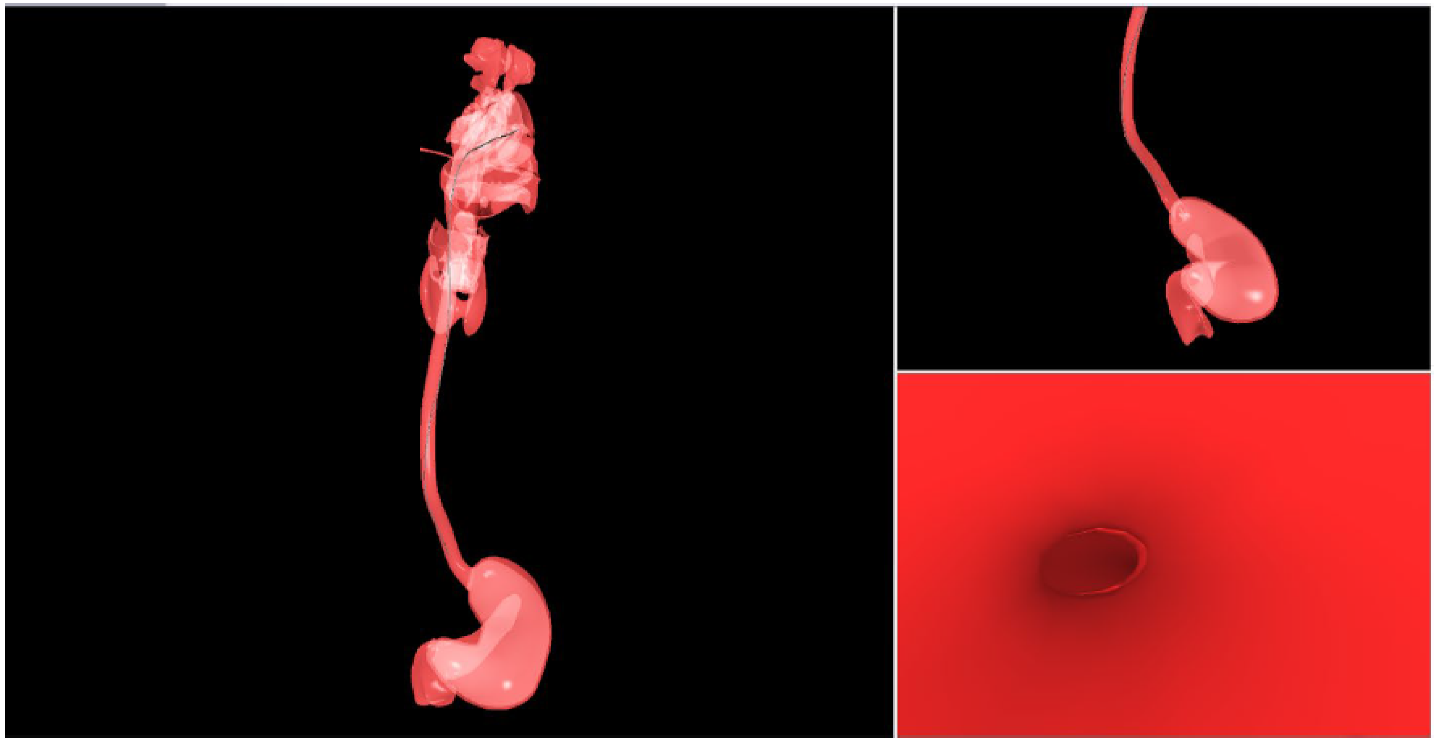
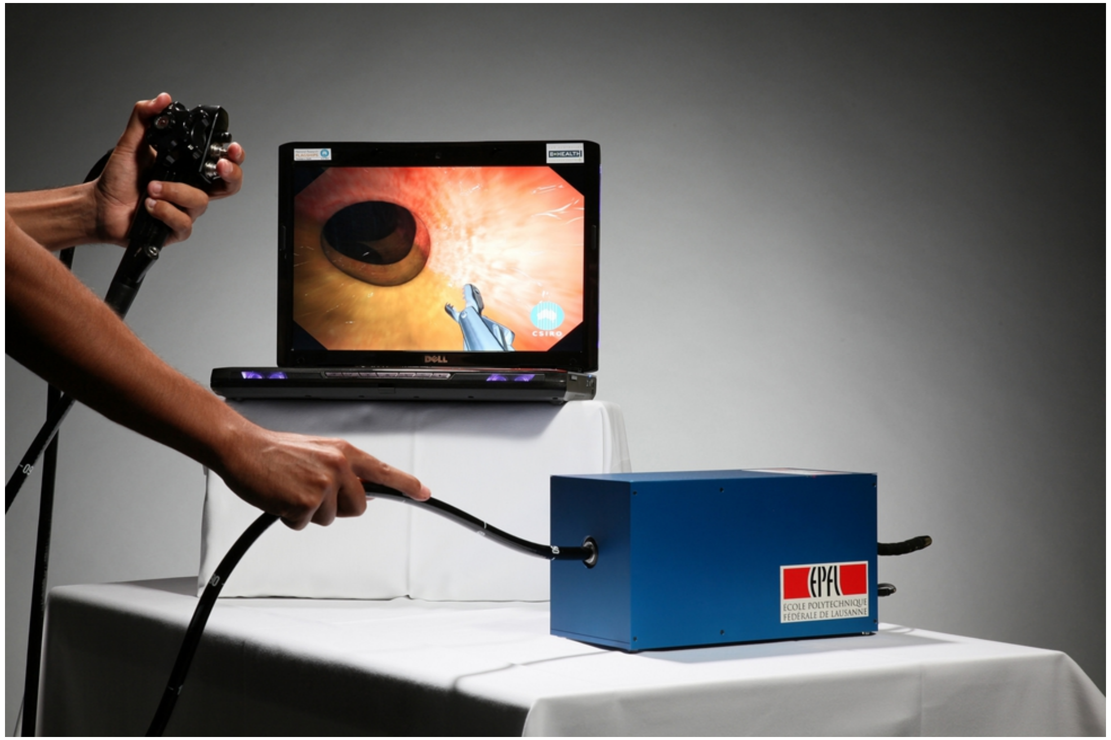
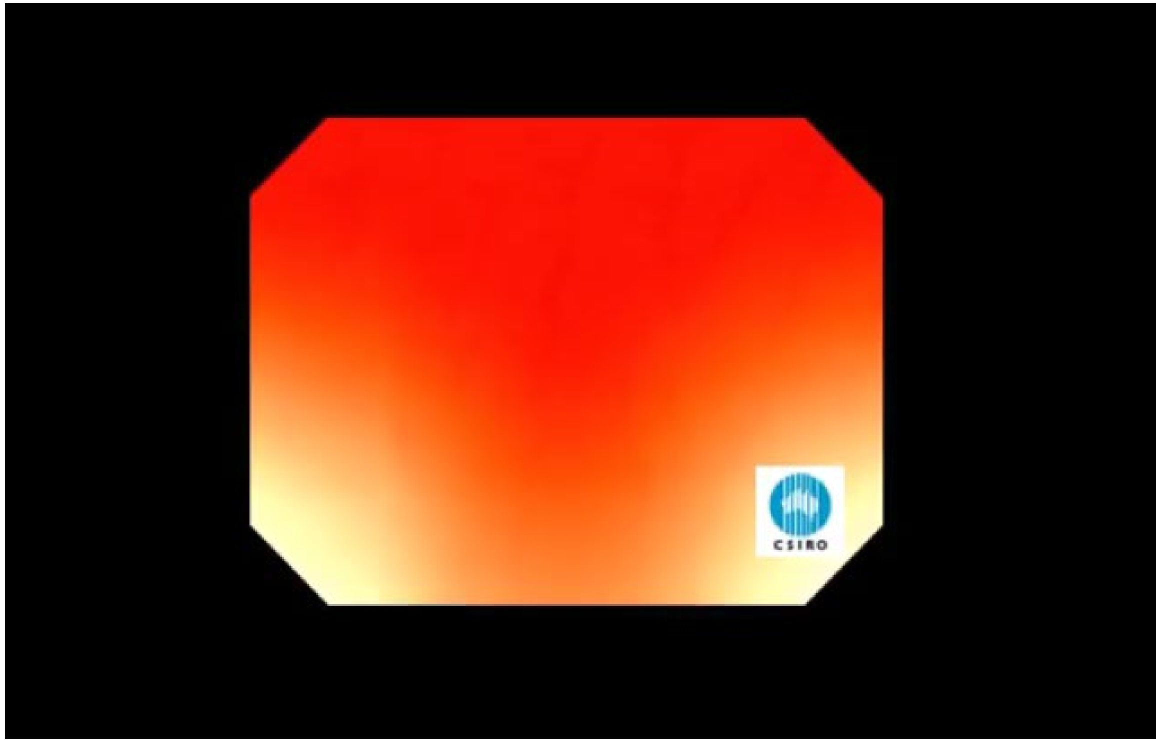


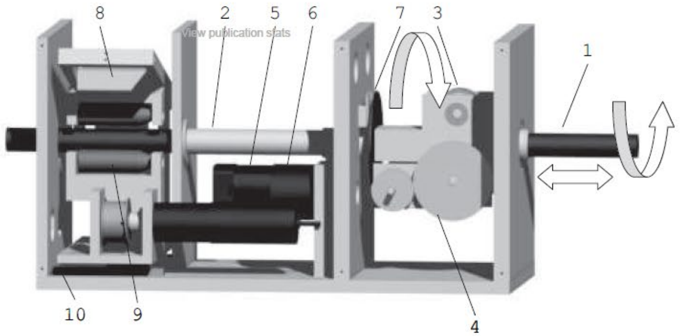
Fig. 7 The catheter can be seen intubated into the nasal aperture with the nasopharyngeal–oesophageal easily passage visualised

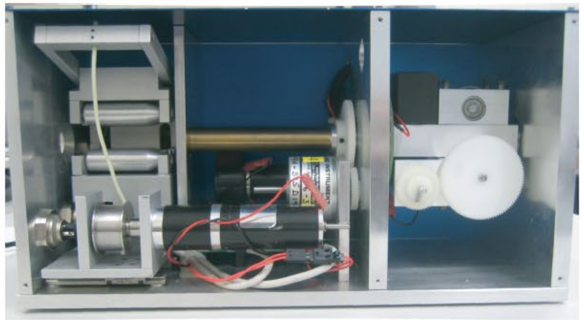
Wen T, Medveczky D, Wu J, Wu J. Colonoscopy procedure simulation: virtual reality training based on a real time computational approach. *Biomed Eng Online*. 2018;17(1):9. Published 2018 Jan 25. doi:10.1186/s12938-018-0433-4

Colonoscopy training: CSIRO'S colonoscopy simulator









Example in deformable organs

- pre-operative medical image projected over the patient

REVIEW
Computer vision and augmented reality in gastrointestinal endoscopy
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Augmented reality in surgery

Definition

- Exercise: