Project – Designing, teaching and controlling a 4th hand

HASLERSTIFTUNG

EPFL

The Team

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SWISS FOUNDATION FOR INNOVATION AND TRAINING IN SURGERY

Real-life examples 4-hands work

Supporting

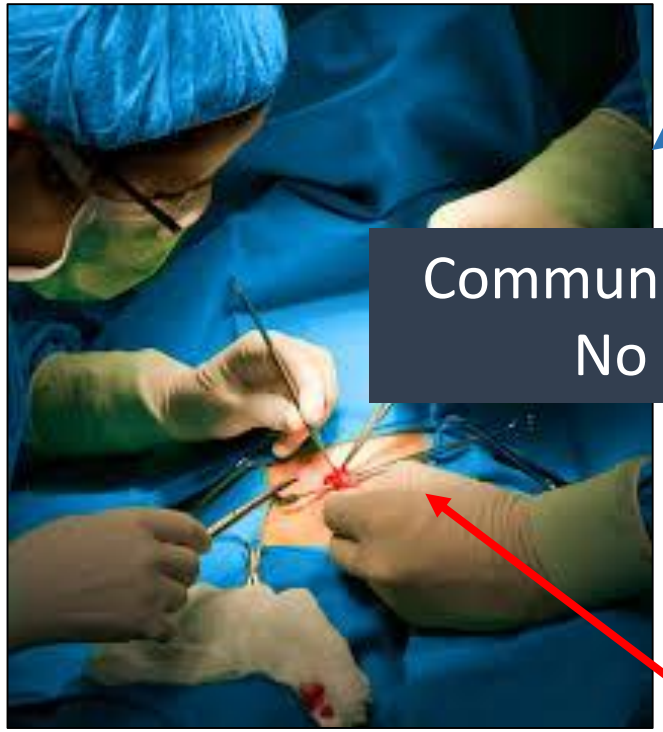
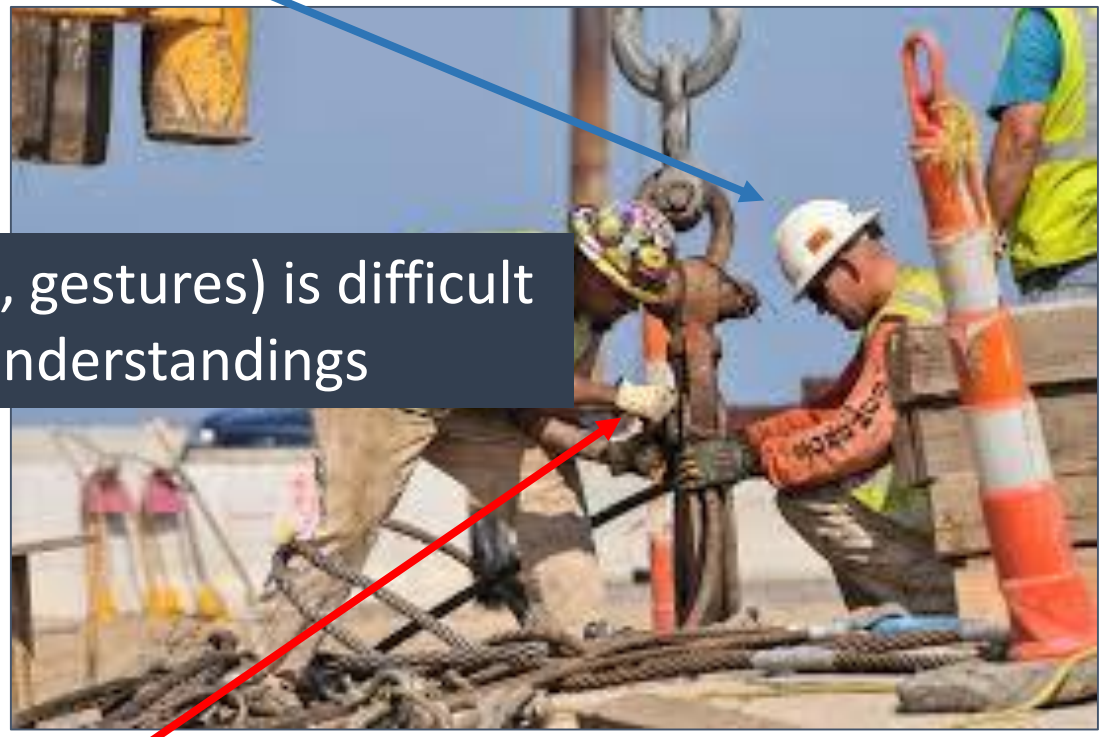


Photo | Surgical Skills Lab

Communication (speech, gestures) is difficult
No room for missunderstandings



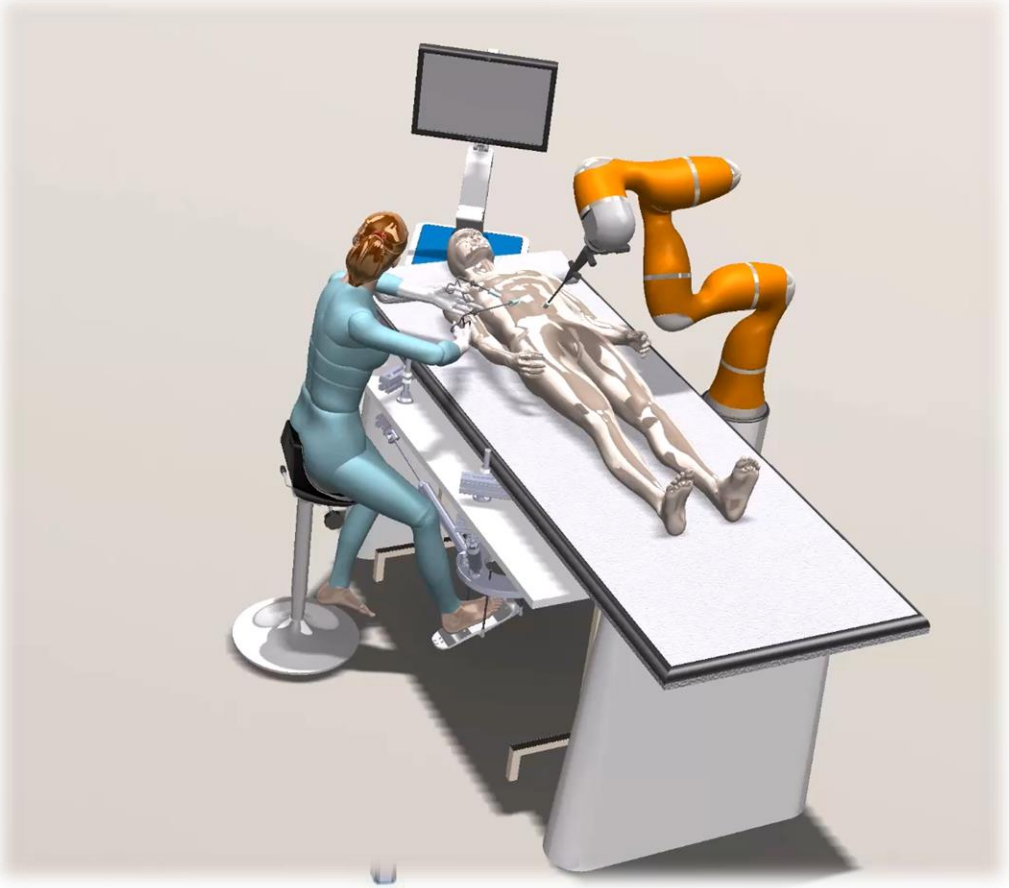
Bross Construction Office - Photo | Glassdoor

Guiding

3-handed laparoscopy surgery!

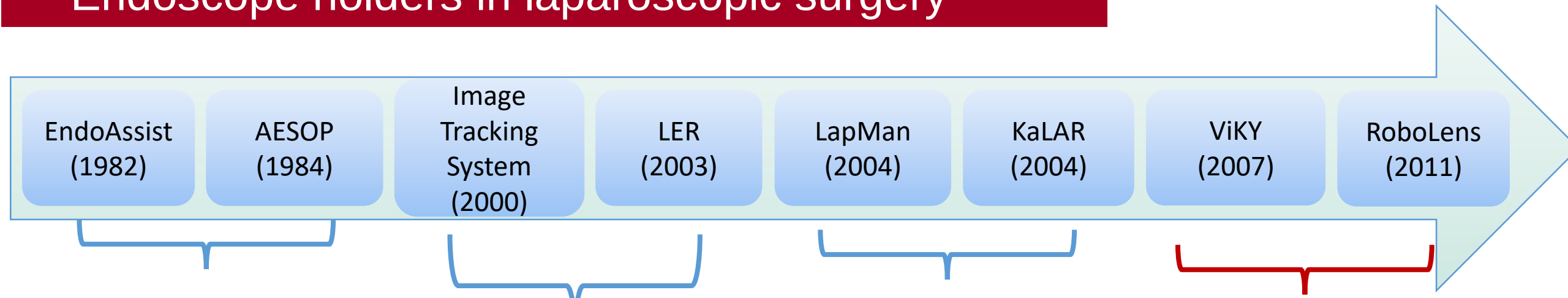
Photo | Surgical Skills Lab

From 2 to 3



Collaboration with SFITS – University Hospital Geneva

Endoscope holders in laparoscopic surgery



Head motion controlled

Voice activated

Commanded by joystick

Commanded by footswitch

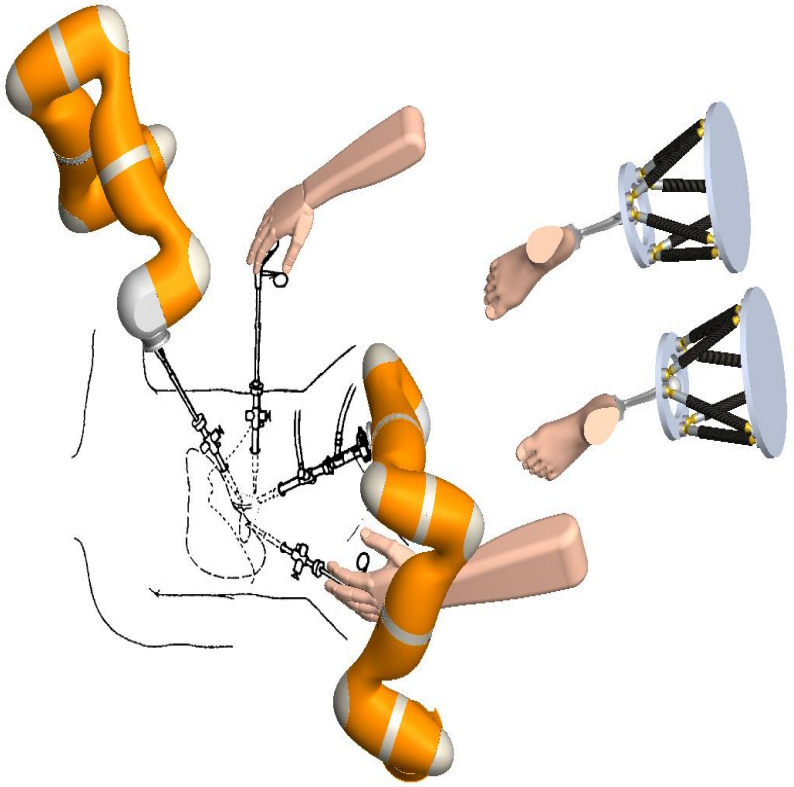
All of these systems are tele-operated!

Only control in position – no control in force

4-handed laparoscopy surgery!

Photo | Surgical Skills Lab

From 2 to 4



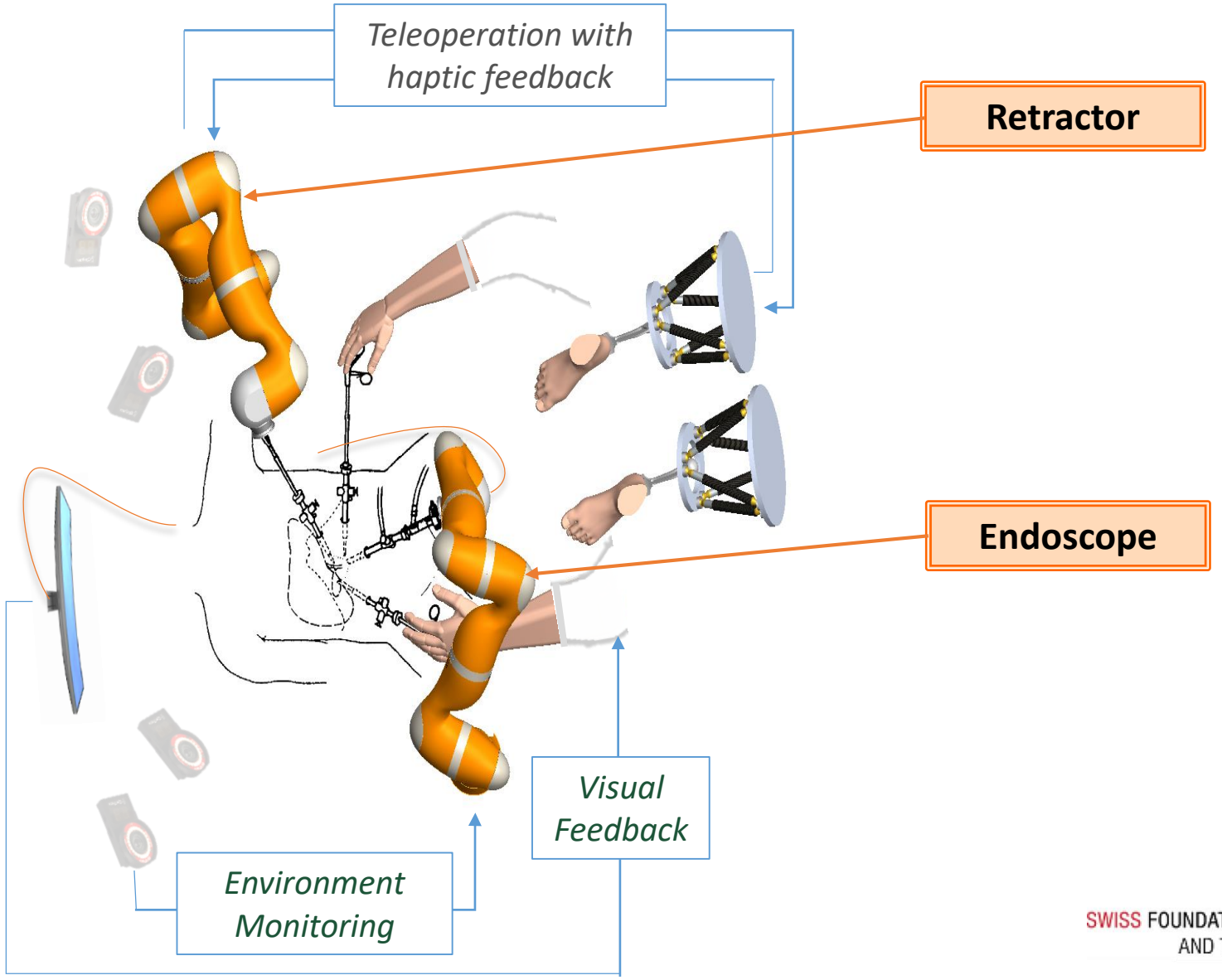
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Fully Autonomous System!

4-hands robotic system for industrial use, Asada's group, MIT (Parietti et al., ICRA 2016)

Our goal: shared-control for more dexterity in each arm

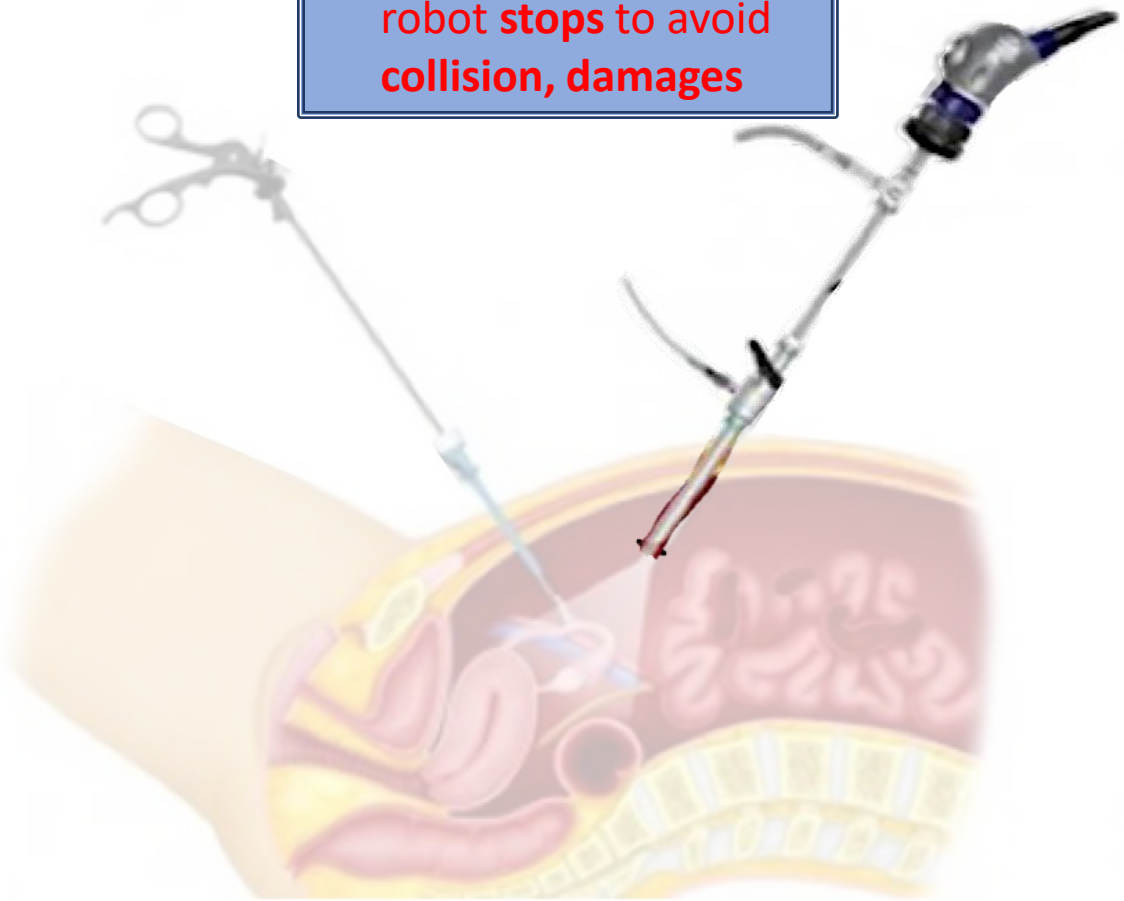
Project's Target



Project's Target

- Shared control with the robot
  - **Safety**

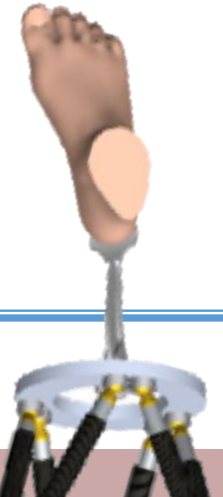
- Despite the foot, the robot **stops** to avoid **collision, damages**



Foot workspace

Too far *for the desired endoscope movement*

Haptic feedback



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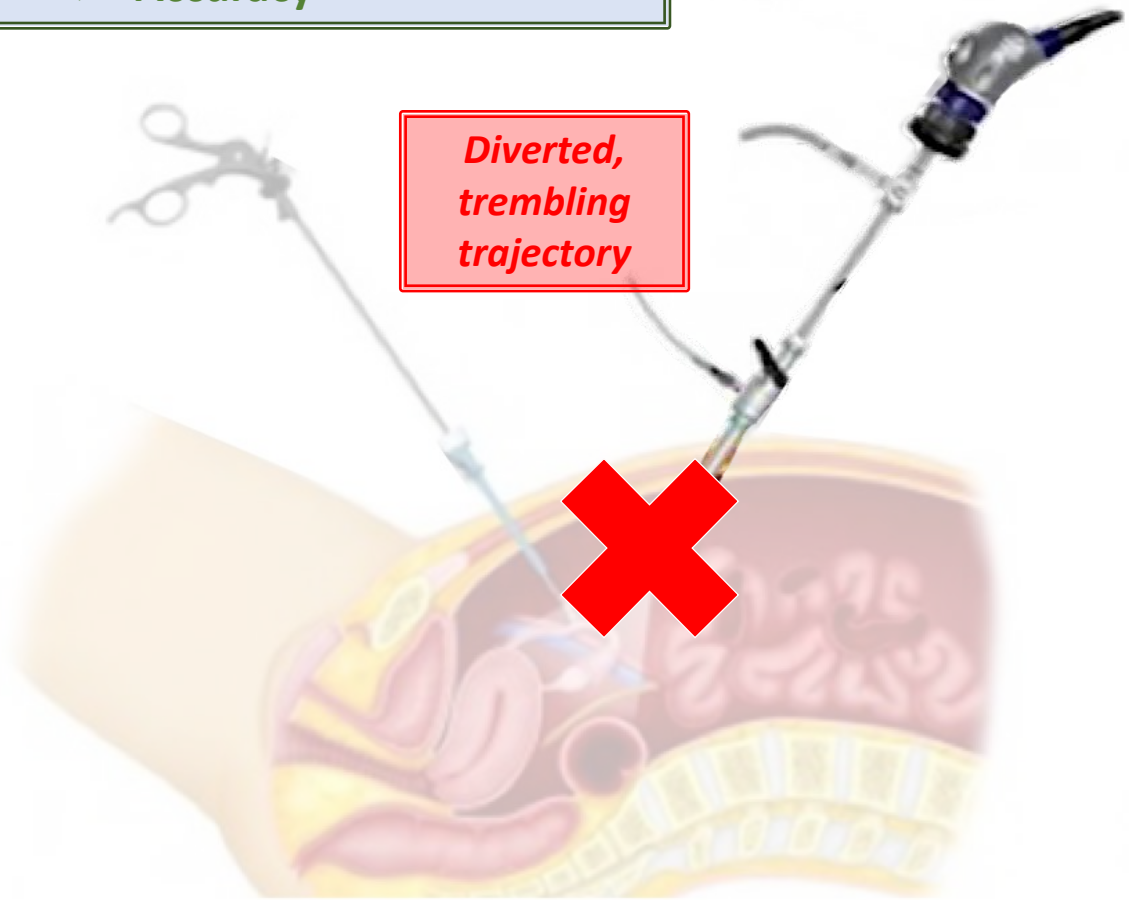
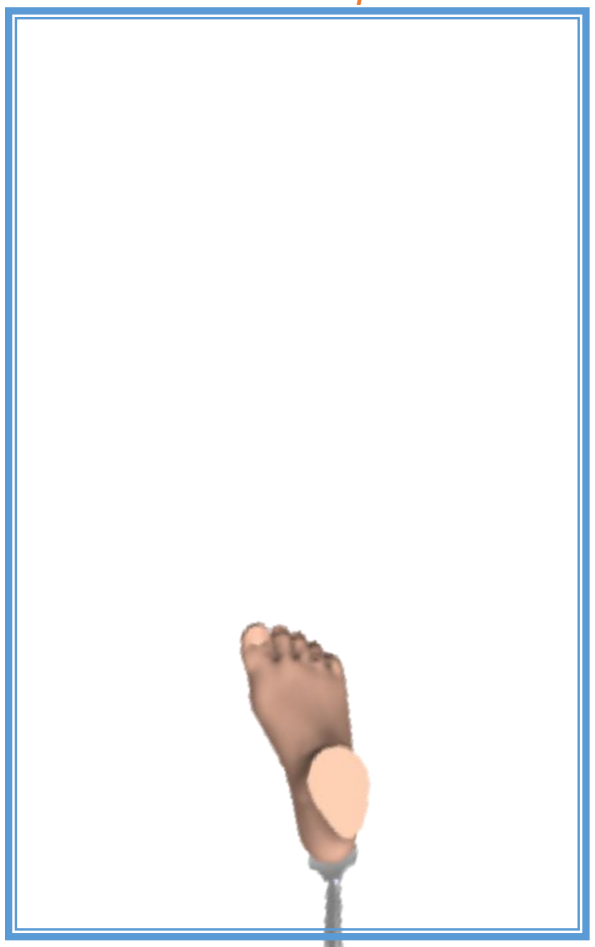
Project's Target

- Shared control with the robot
  - Safety
  - **Accuracy**



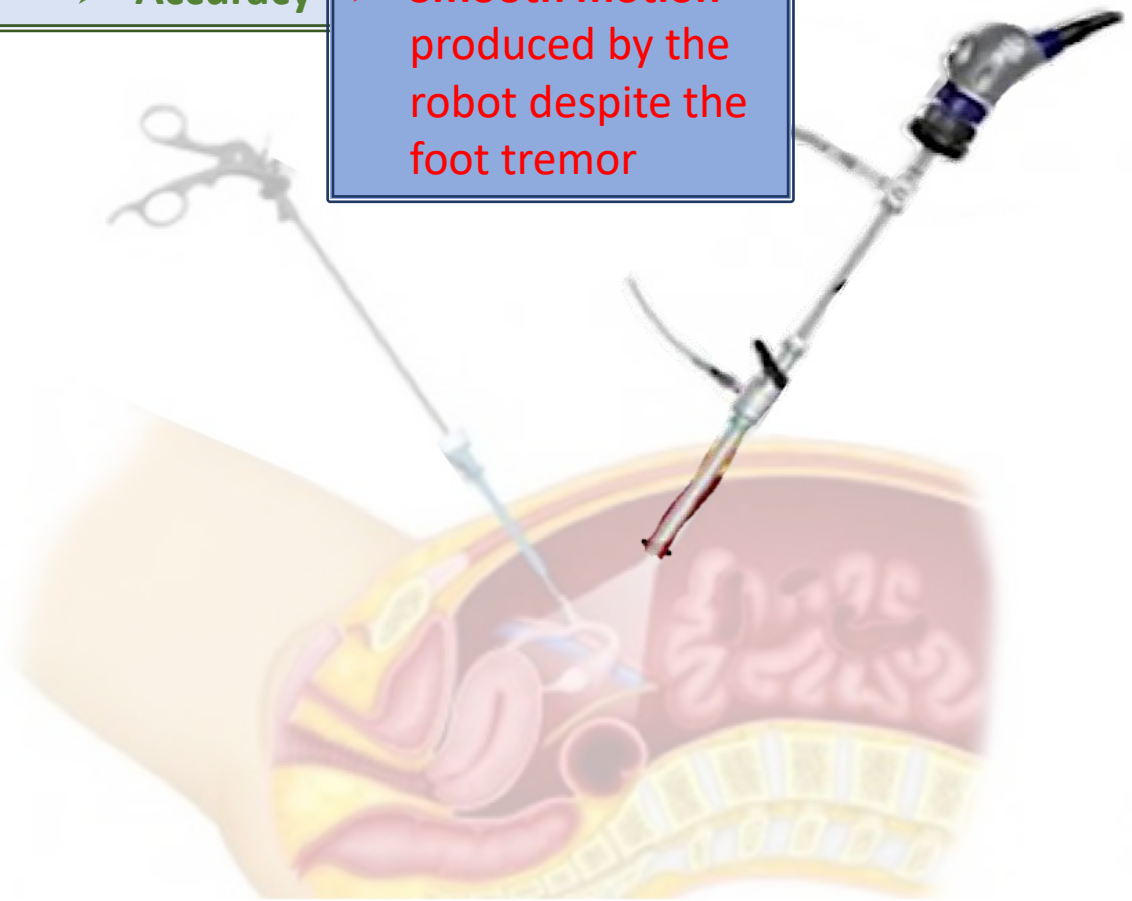
Foot workspace



SWISS FOUNDATION FOR INNOVATION AND TRAINING IN SURGERY

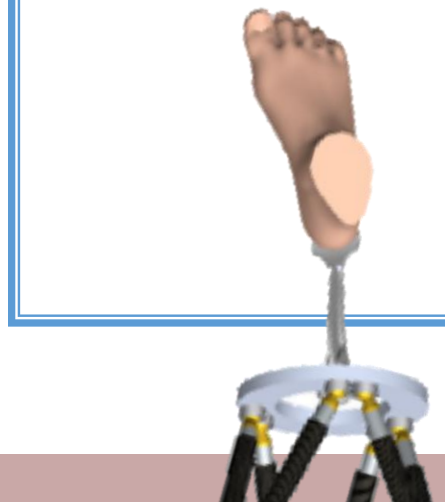
Project's Target

- Shared control with the robot
  - Safety
  - **Accuracy**
  - **Smooth motion** produced by the robot despite the foot tremor

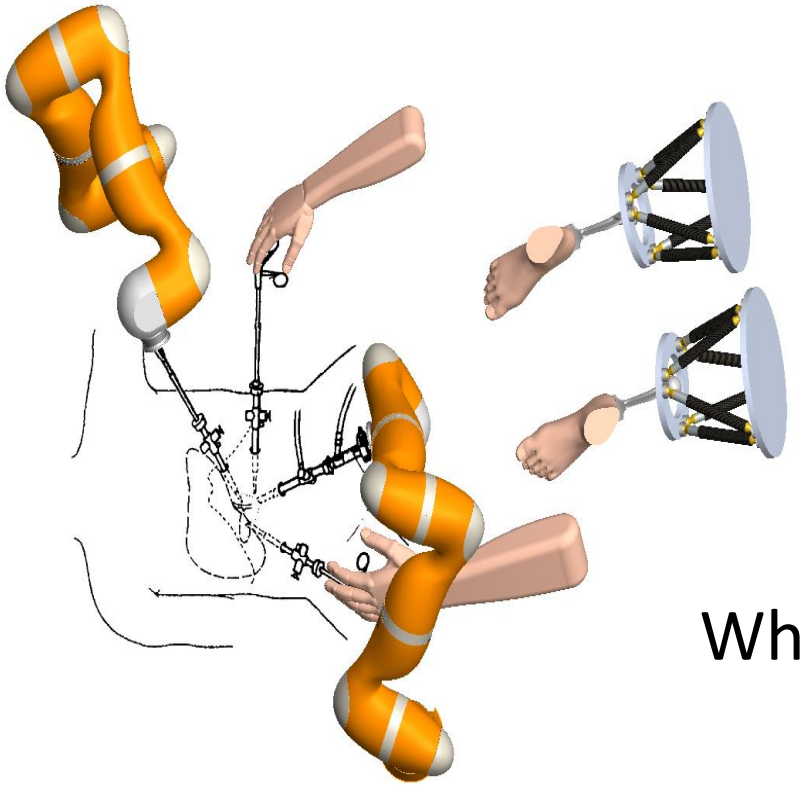


Foot workspace

Haptic feedback



SWISS FOUNDATION FOR INNOVATION AND TRAINING IN SURGERY



Which interface for the feet?

Training Time

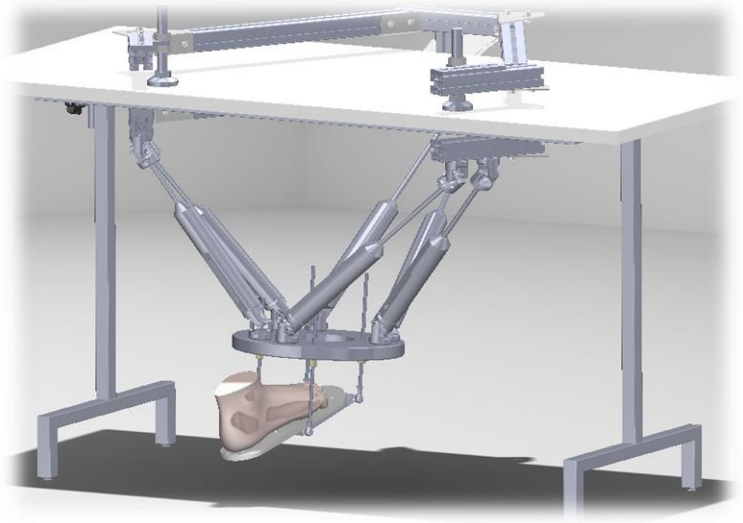
Hours

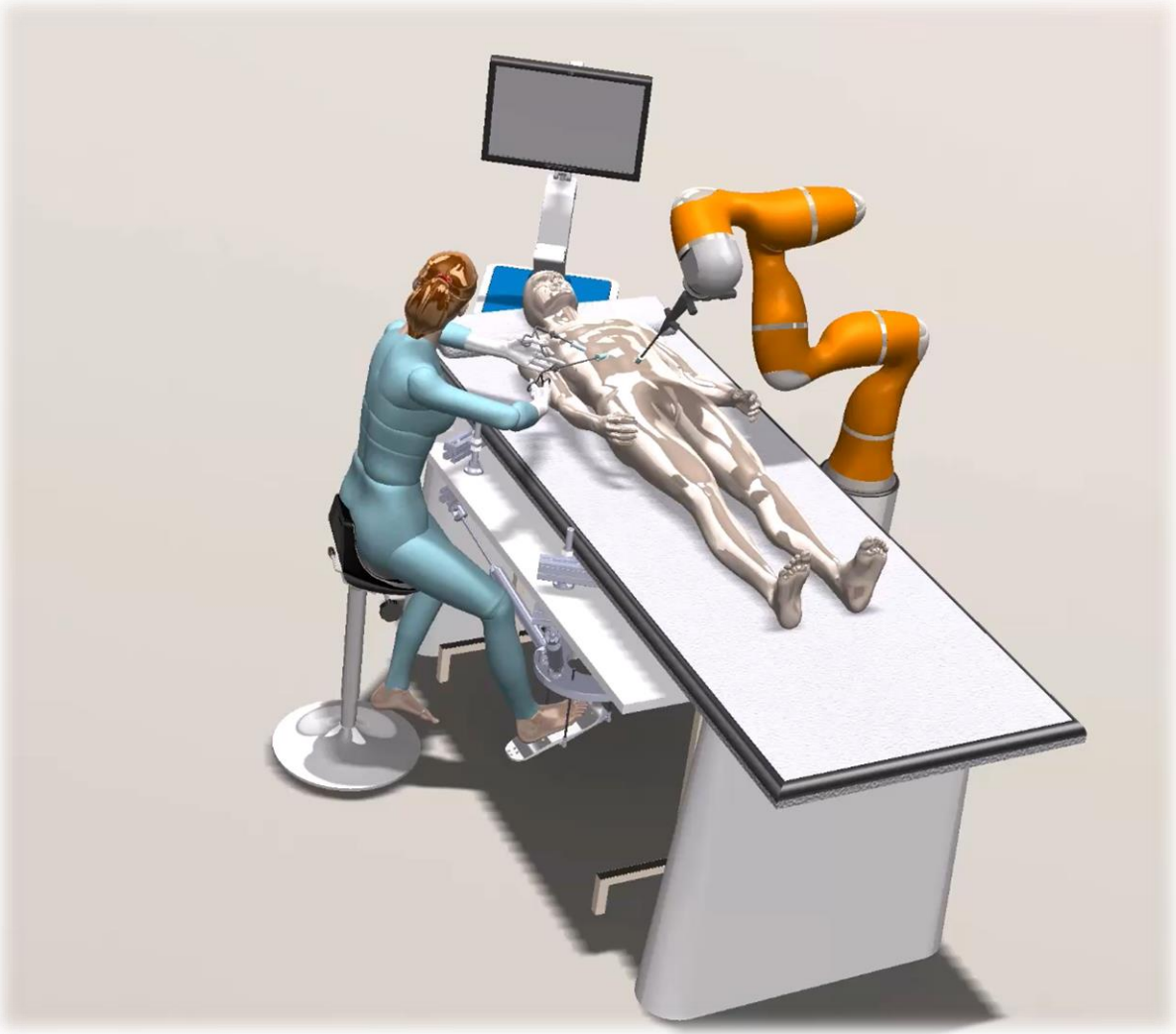
Simple, e.g. driving

Years

Complex e.g. organist

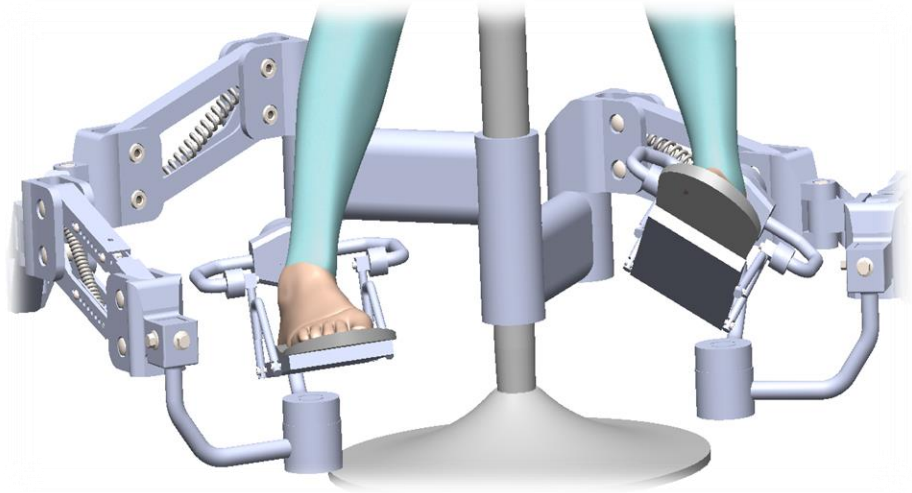
Envisioned implementation





Other alternatives

Inspired from the design of Fraunhofer Institute (Ge)

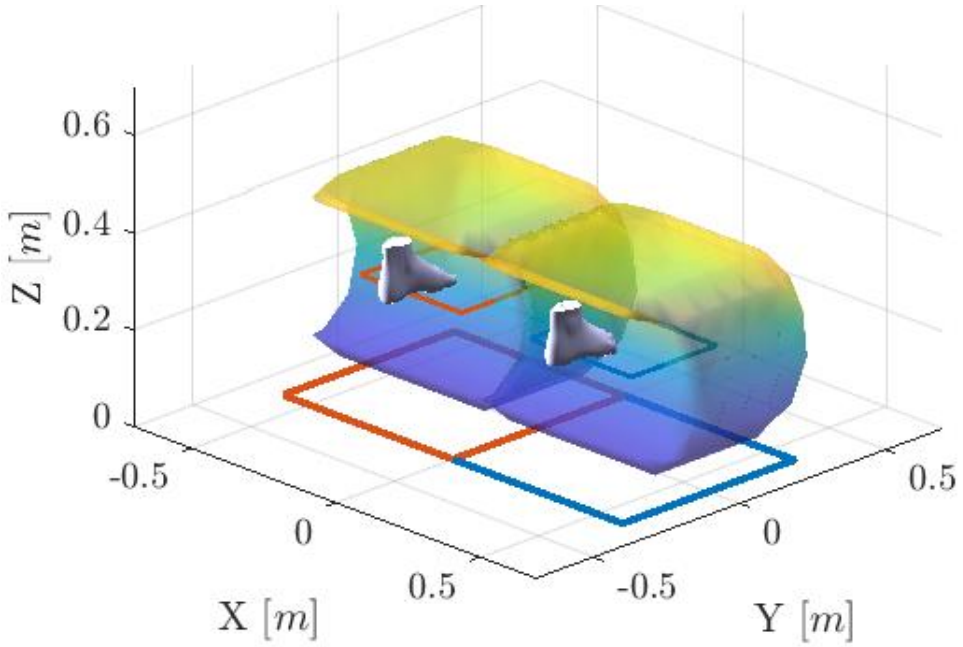


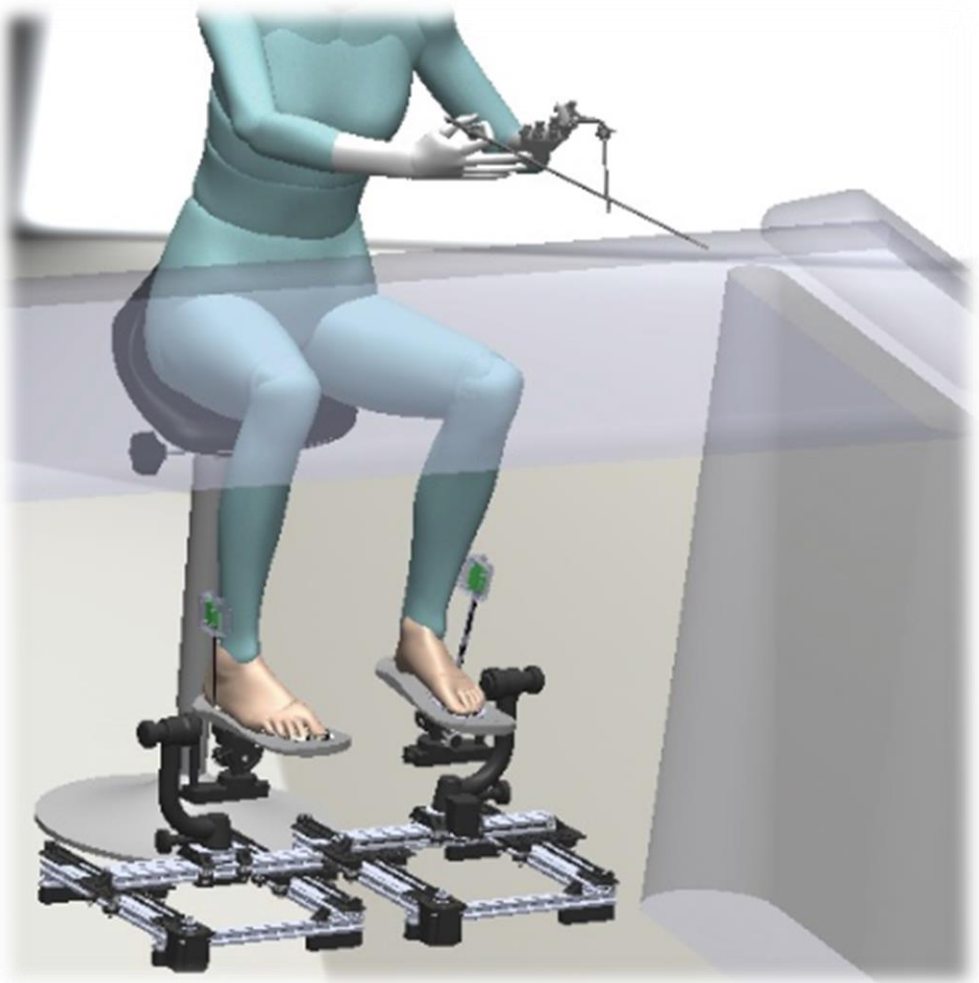
- ↗ Workspace
- ↗ Backdrivability/control
- ↘ Foot print

- ↗ Passive
- ↗ Gravity compensation
- ↘ Haptic feedback

Adopted solution

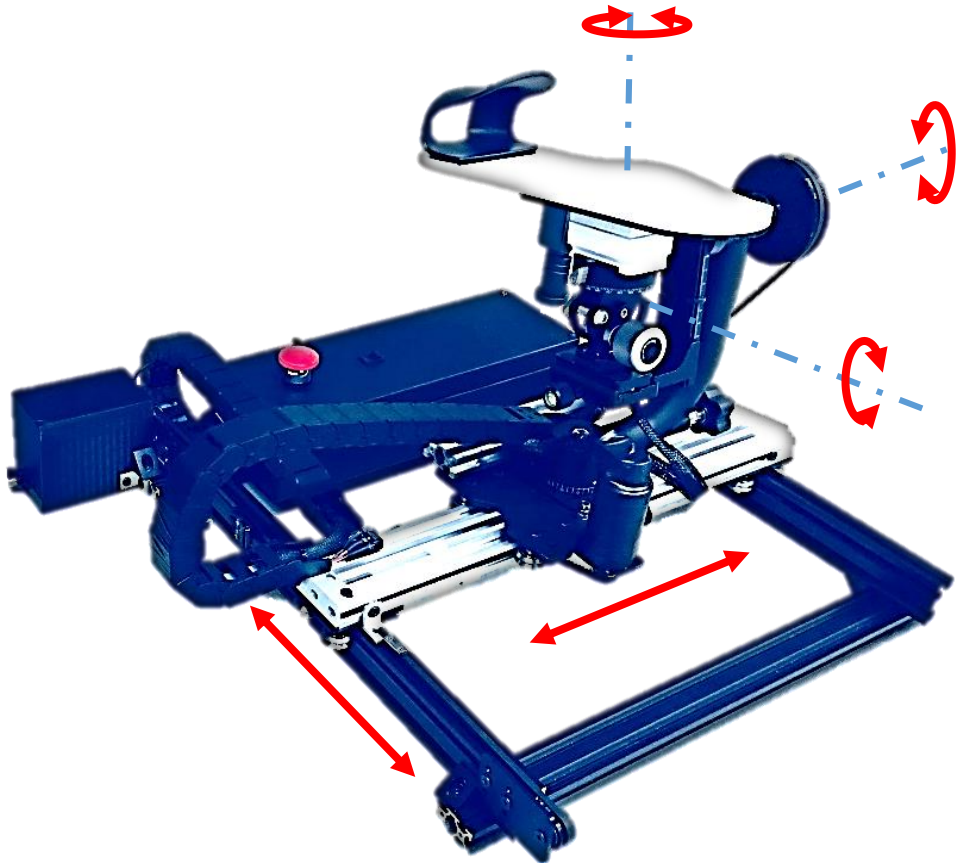
- Bipedal
- 5 active Dofs (**XY** and **orientations**)
- Large translational workspace
- Implements haptic feedback

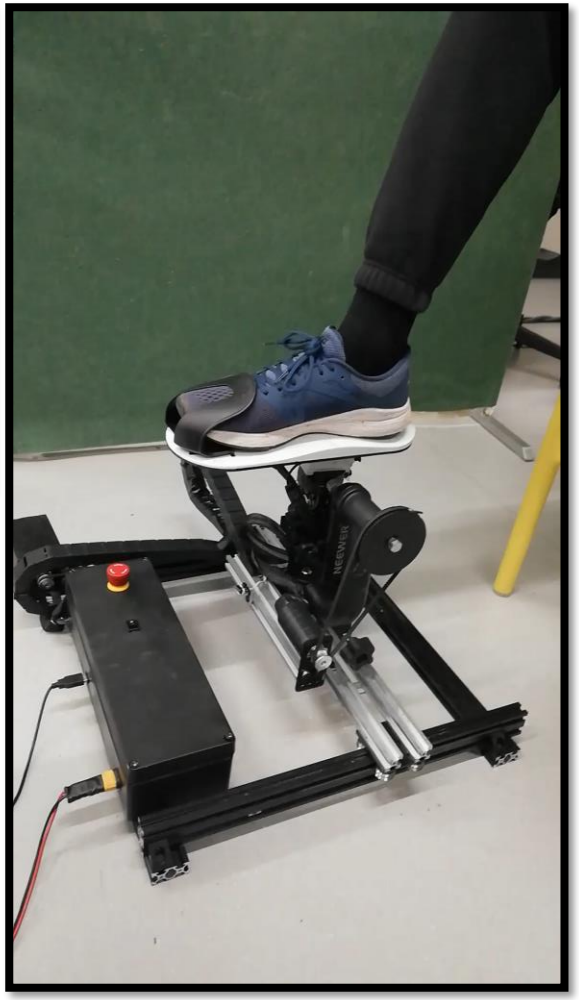




First prototype

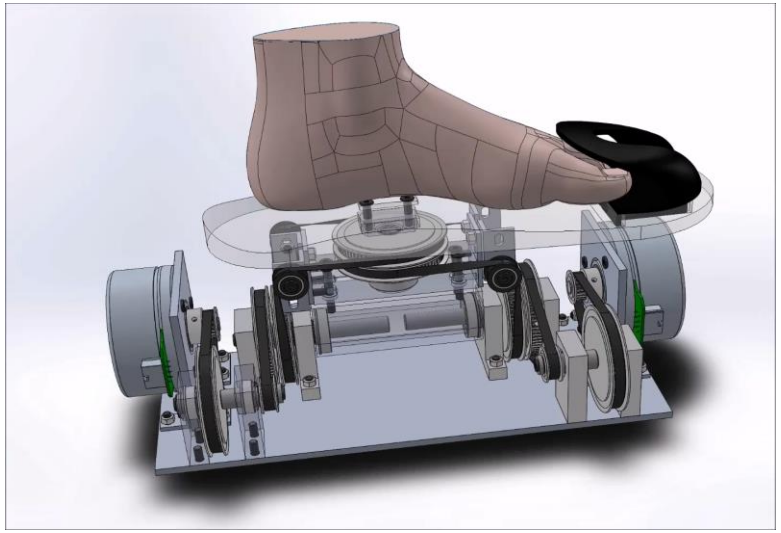
- ***5DoF** & 3D **Active Force Feedback***
- *Small 59x59x35 cm*
- *Proof of concept to investigate psychophysics and motor control*

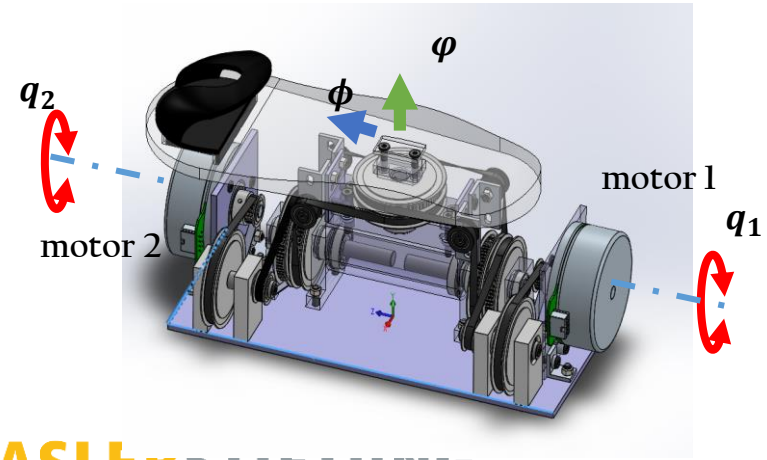


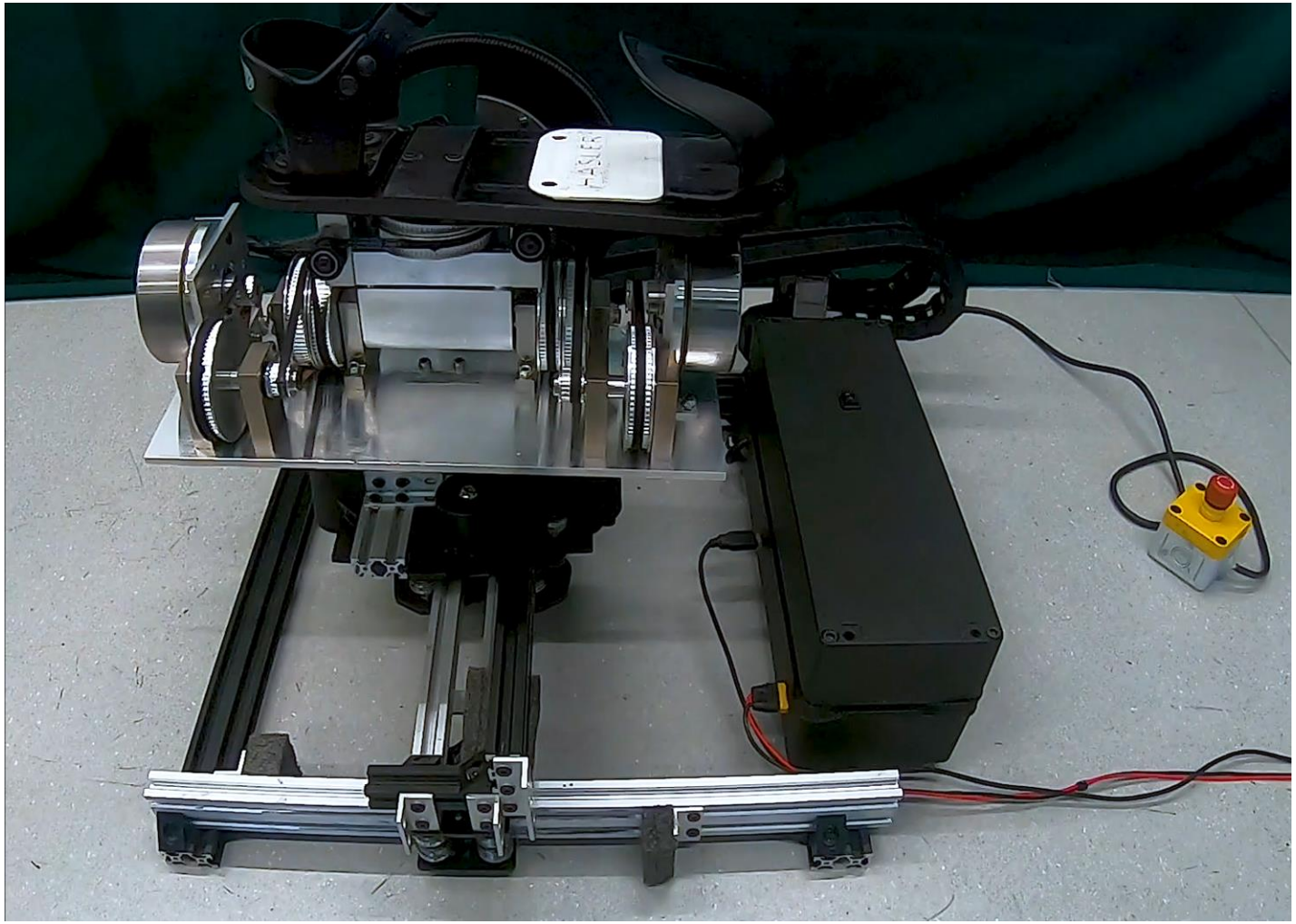


Final prototype

Differential Mechanism Roll & Yaw -> 2x Torque for Isolated Motions

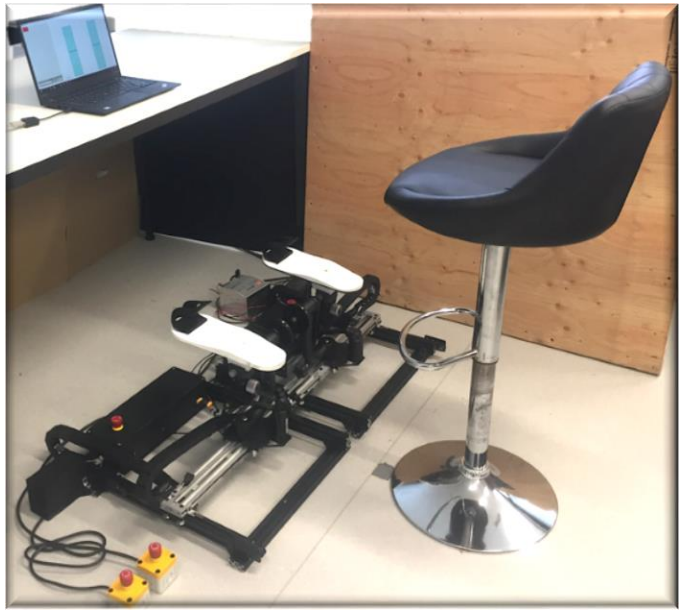






Exploring precision of control with the foot

Factor Evaluation of Feet Position Control with Visual Feedback



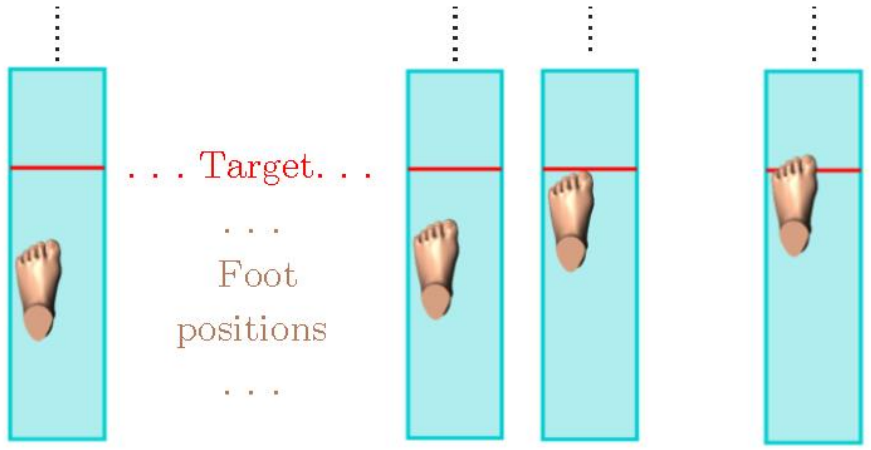
10 participants, 5 randomly selected for analysis

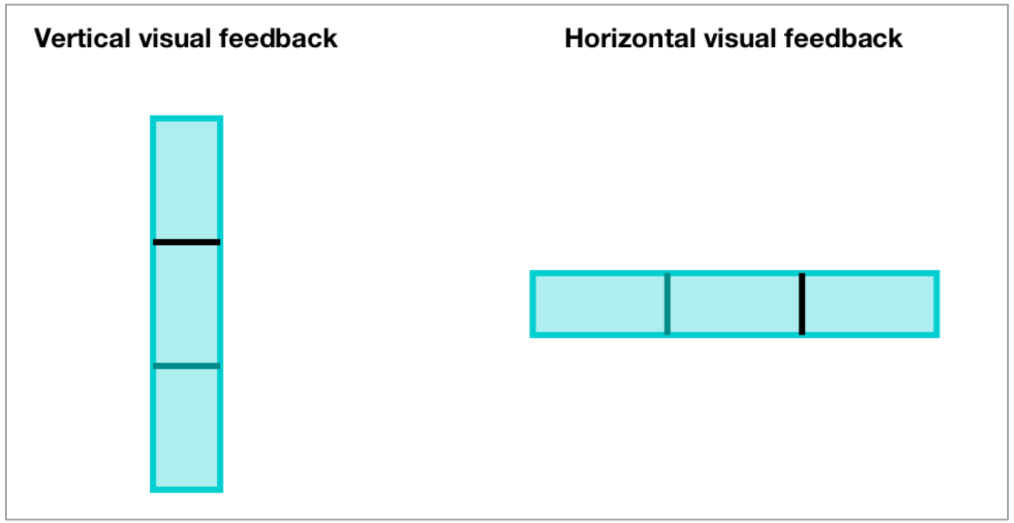
Full Factorial Design:

- ✓Effect of DOF
- ✓Visuomotor Transformation
- ✓Foot Laterality
- ✓Inter-subject variability (participant)

Exploring precision of control with the foot

Factor Evaluation of Feet Position Control with Visual Feedback





Factor	Levels
Foot Motions DOF (α_i)	X, Y , PITCH (θ)
Visual Feedback Orientations (β_j)	Horizontal, Vertical
Foot Laterality (γ_k)	Left, Right
Participant (η_n)	P3, P4, P6, P11, P19

Exploring precision of control with the foot: results

Precision of control:

- Control in position is accurate: ~1cm
- Control of angular movement: ~5deg
- 50% variance across subjects

Speed of control:

- Speed of motion in position is fast: 50 mm/sec.
- Speed of angular motion slower: 20 deg/sec.
- Speed of motion of left foot slightly slower – 15%

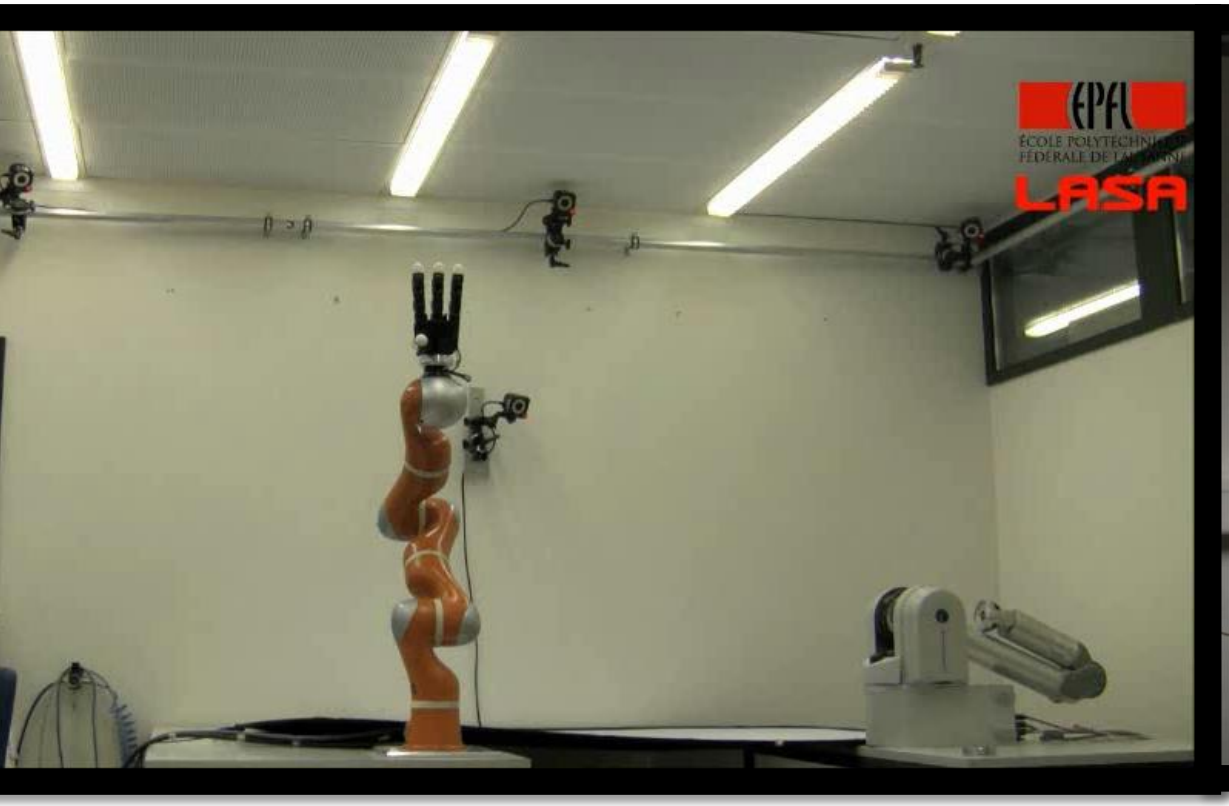
Precision in control of force and haptic perception at the foot?

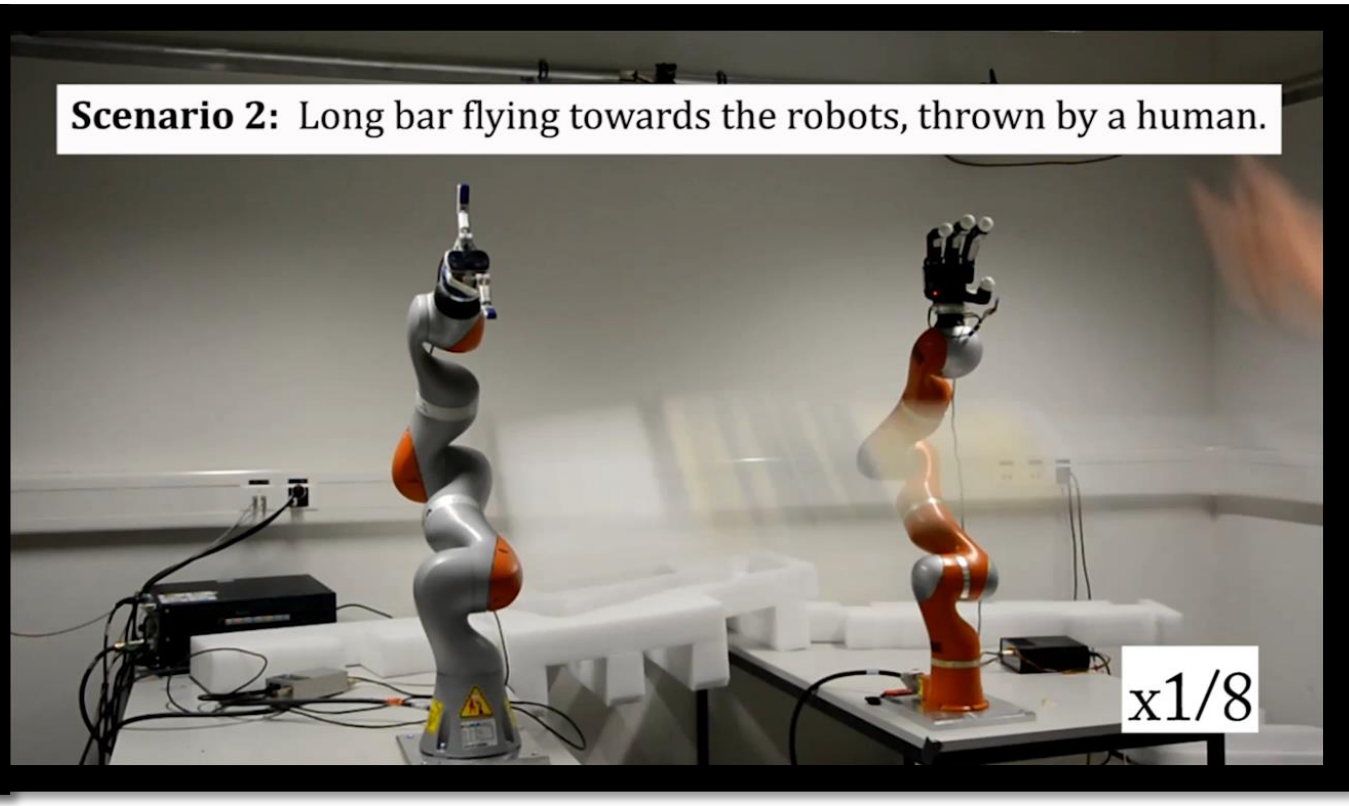
Effect of increasing number of degrees of freedom controlled?

Haget et al, Progress in Motor Control, 2019

Mode of Control: Tele-operation

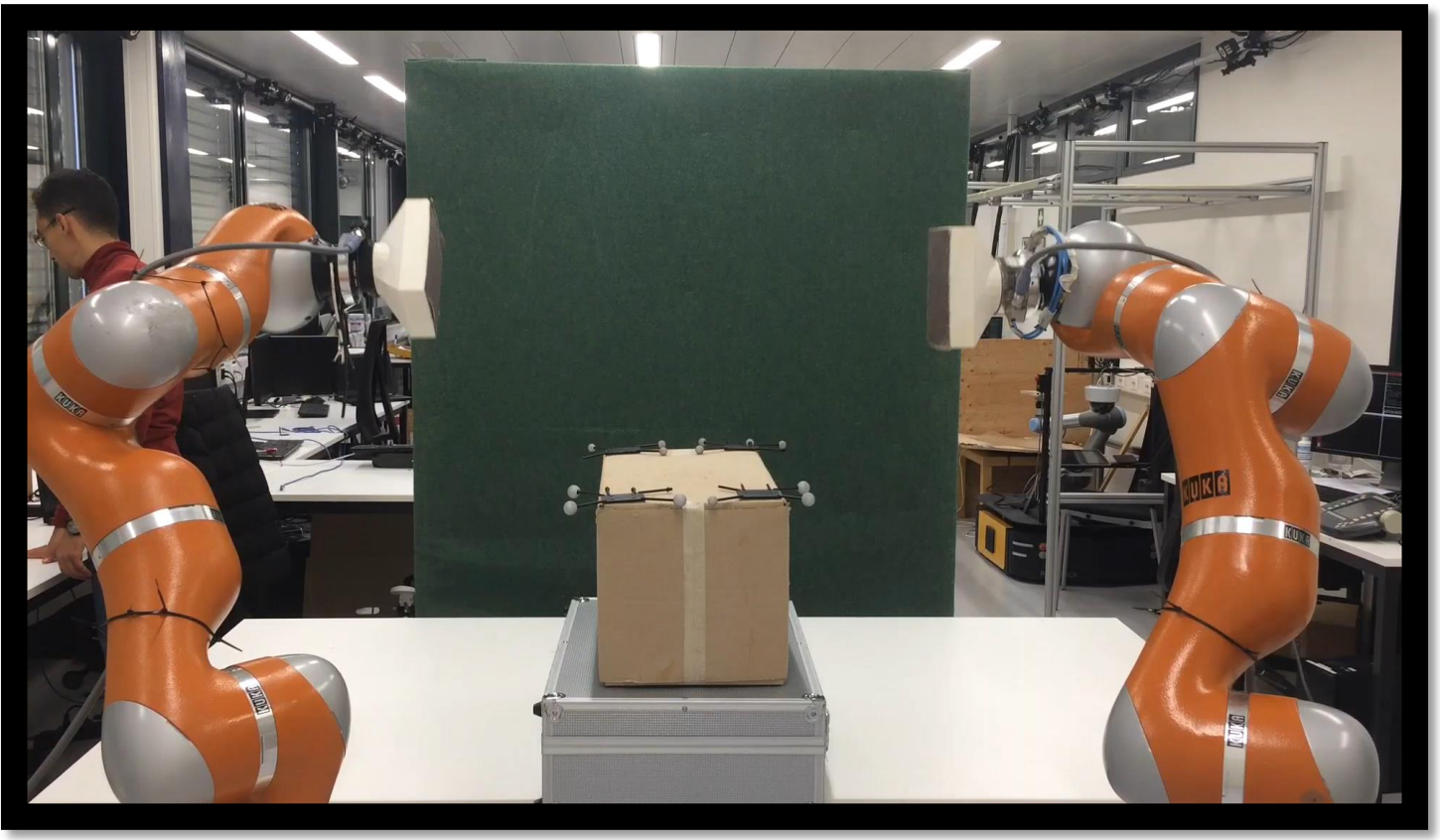
Mode of Control: Autonomous

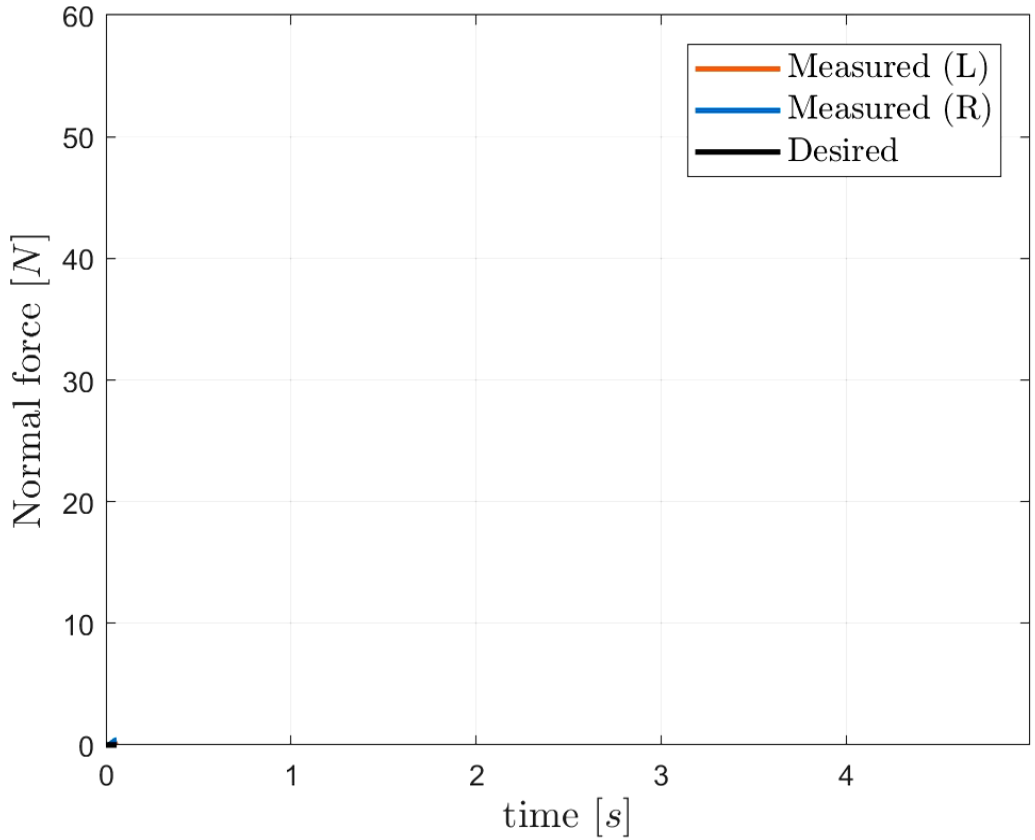




Kim et al, T-RO best paper 2014,
Mirrazzavi et al, best student paper RSS 2016

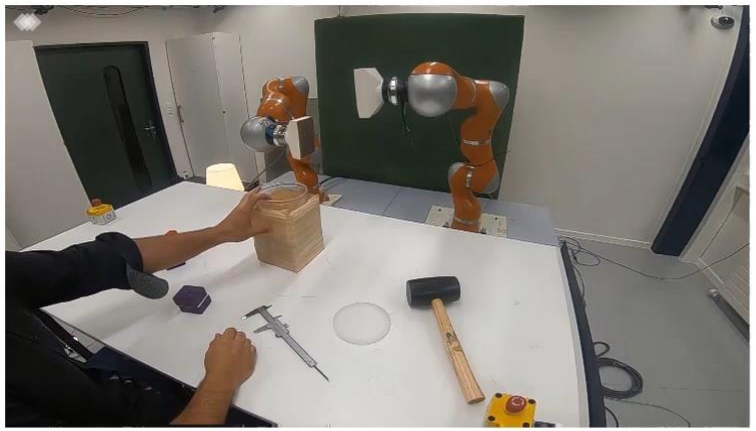
Mode of Control: Autonomous

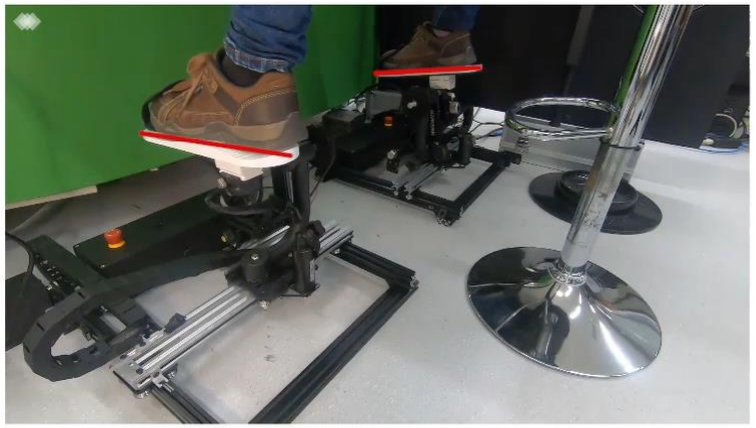


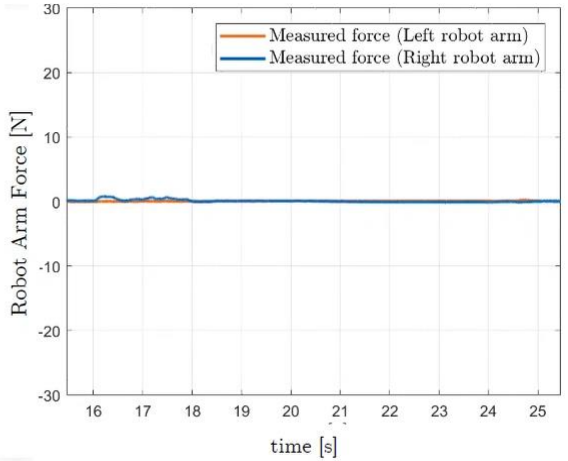


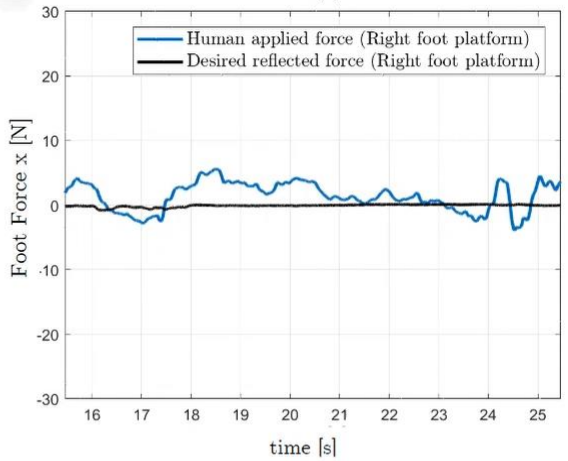
Amanhoud et al, RSS 2019

Mode of Control: Shared-control



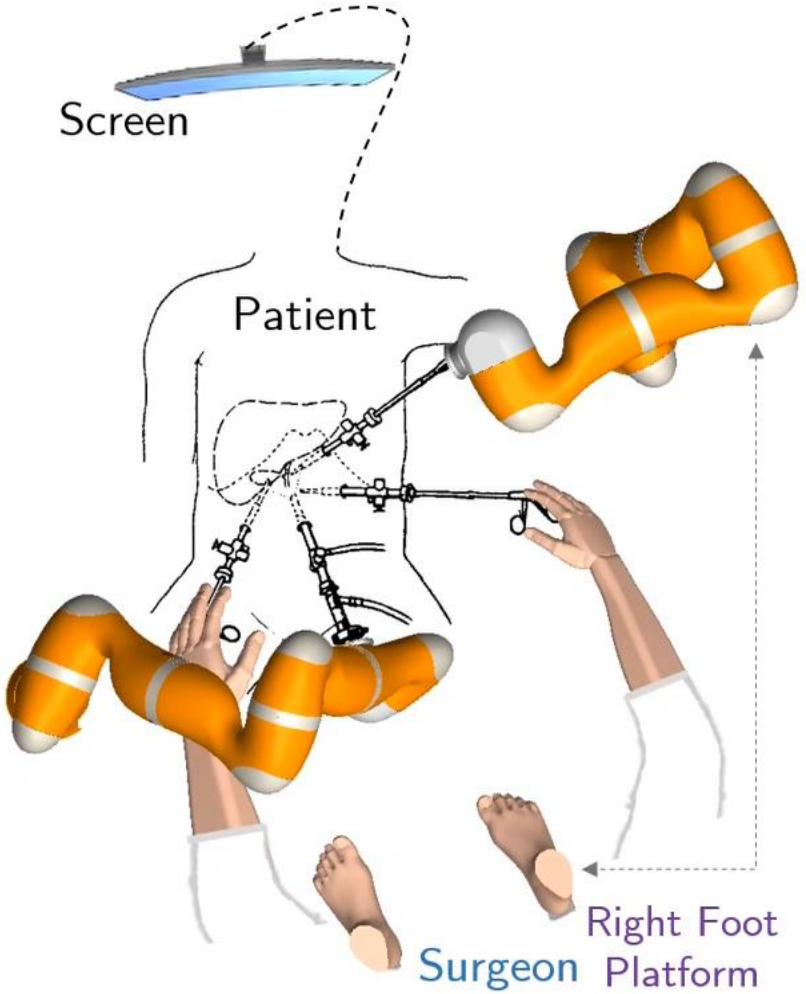






Hernandez et al, AAAI 2019

Four Arm Laparoscopic Surgery Via Foot Interfaces



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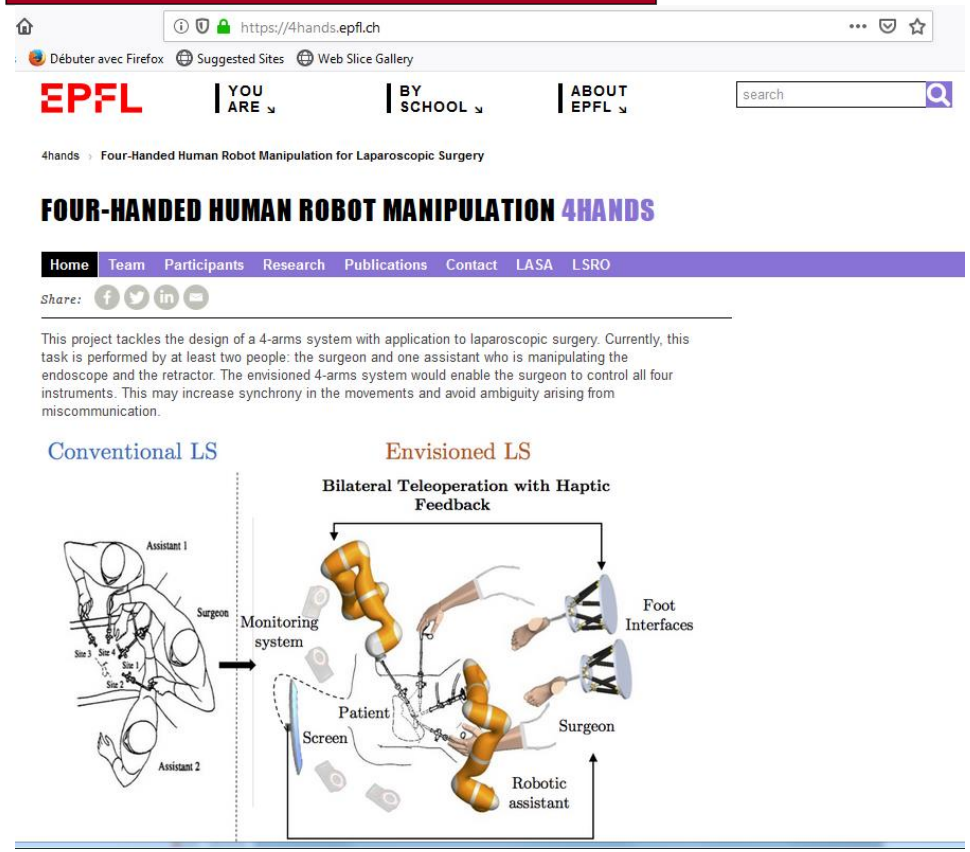
Website

https://4hands.epfl.ch/



Publications

- Amanhoud et al. (2019). **A Dynamical System Approach to Motion and Force Generation in Contact Tasks**. In Proceedings of Robotics, Science and Systems (RSS).
- Haget et al. (2019). **Learning to control semi-autonomous robotic arms with your feet for four-handed laparoscopic surgery.** Progress in Motor Control XII: Movement Improvement (PMC).
- Hernandez, J. et al. (2019) **Four Hands Manipulation Via Feet Interfaces. In Proceedings of AAAI 2019 Fall Symposium Series.** In Proceedings of AAAI Fall symposium series, 2019.
- Amanhoud et al. (2019). **Force Adaptation in Contact Tasks with Dynamical** Systems, *Submitted* to Int. Conf. on Robotics and Automation, ICRA 2020.

Follow-up project

➢ Zeiss industrial grant (Billard) – 100K CHF, 2019-2021

Next Steps

Study of Motor Control

Precision of control at the foot in force and haptic perception

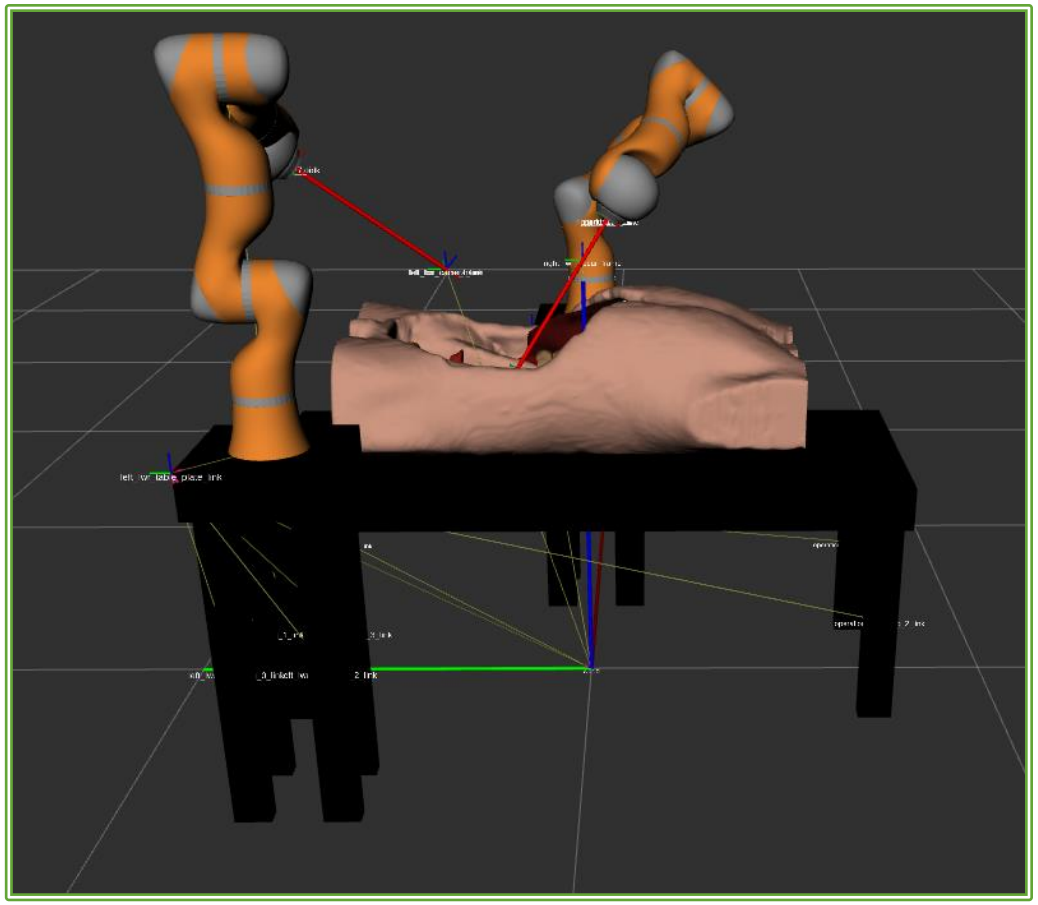
User study with surgeons

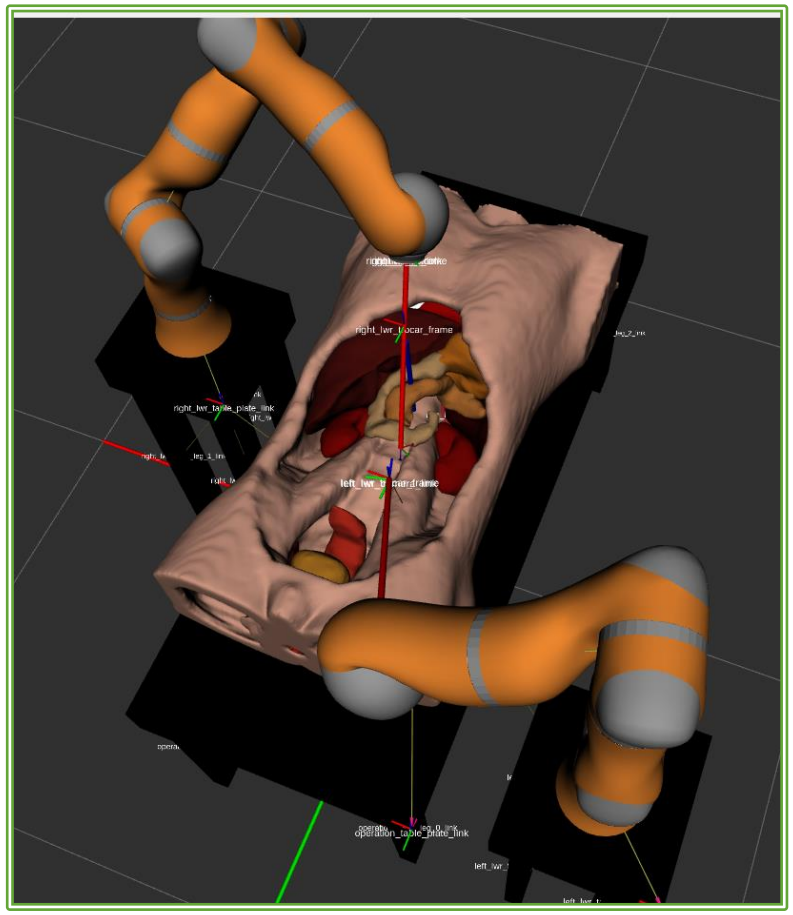
Robot Control

Extend shared control in force and position

Explore coordinated control to ease dexterity

More realistic scenario





More realistic scenario