Haptic Shared Control for da Vinci Surgical Teleoperation with Haply Inverse3

Dr.-Ing. Balint Varga

EKIK Days – March 24-25, 2026.

Our Journey

1825
Universität Karlsruhe

2006
Success in the first round of the Excellence Initiative

2012
KIT Further Development Act (KIT-WG)
- Capacity of employer
- Builder status (Campus East)
- Right to appoint

2021
KIT 2.0
End of the separation into University Sector and Large-scale Research Sector

1825 - 2008 | 2009 - 2011 | 2012 - 2020 | 2021 →

1956
Forschungs-zentrum Karlsruhe GmbH

2009
Foundation of Karlsruhe Institute of Technology

2016
New Vice President Transfer and International Affairs

2019
Success in the Excellence Strategy
e.g.100 professorships program with a focus on tenure-track professorships

2023
New Vice President Digitalization and Sustainability

KIT in Figures

2024

415
Professors

22 761
Students

10 107
Employees

58
New spin-offs and start-ups

6
Locations (200 ha area)

1 730
International scientists

3 683
Doctoral researchers

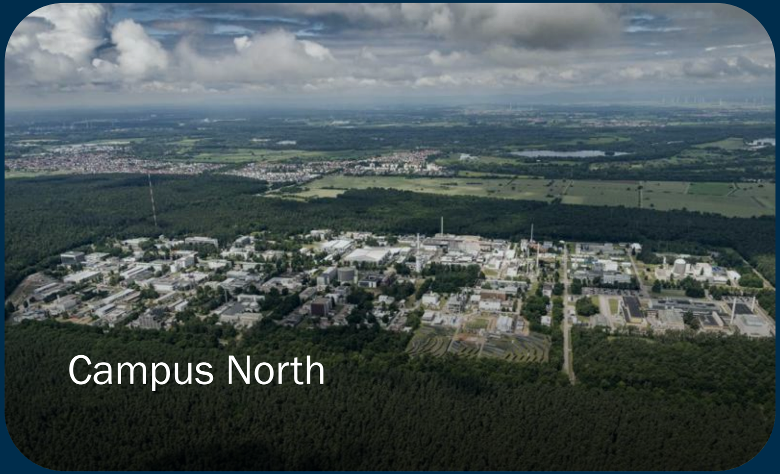
337
Trainees

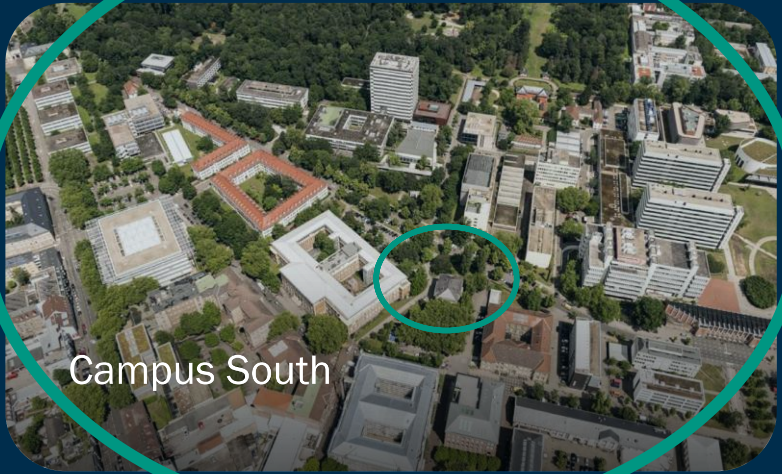
48
Patent applications

Budget
1,225.6 million euros

30%	state funds
30%	federal funds
40%	third-party funds

One KIT – Multiple Locations





IRS at a Glance

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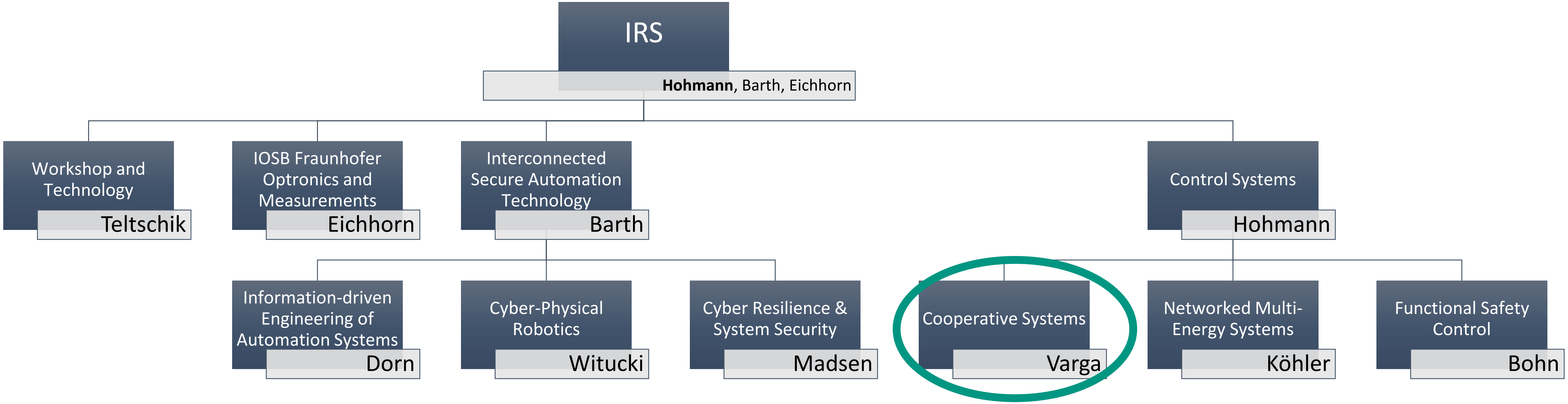
Organization



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Motivation

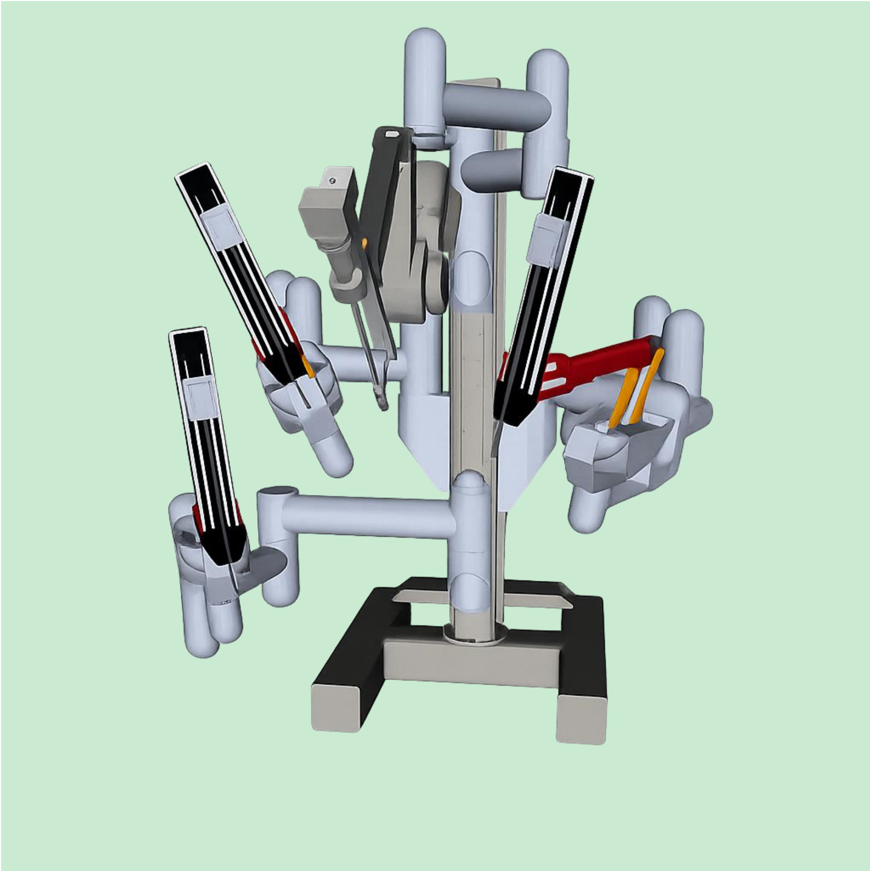
Why Haptic Feedback Matters in Robotic Surgery?

The Problem

In teleoperated robotic surgery, the surgeon is physically separated from the patient. All natural tactile and force feedback is lost.

Consequences:

- Increased tissue forces and damage risk
- Steeper learning curve for novice surgeons
- No tactile distinction of tissue properties
- Reliance on visual cues alone



The Haptic Gap in Surgical Robotics

0 N

Force feedback in
da Vinci Xi/Si

−43%

Tissue forces with
da Vinci 5 FF (2024)

g=1.50

Meta-analysis: accuracy
improvement with haptics

Key Insight: Haptic feedback demonstrably improves surgical task performance. Yet the da Vinci 5 is proprietary and closed – researchers cannot modify the feedback architecture, integrate custom guidance, or study alternative modalities.

1. State of the Art
2. Theory of Shared Control
3. Haply Inverse3 and da Vinci
4. Feasibility Study

State of the Art

Haptic Feedback in Surgical Robotics

Key findings from two decades of research

da Vinci Research Kit (dVRK)

- Open-source platform at 30+ institutions. Native MTMs lack force feedback. External devices (Sigma.7, Omega.7) used as replacements. [Kazanzides 2014, Saracino 2019]

Sensory Substitution

- Visual, auditory, vibrotactile, and cutaneous alternatives to direct force feedback. Visual overlays most effective for novices. Cutaneous "sensory subtraction" guarantees stability. [Kitagawa 2005, Meli 2014]

Virtual Fixtures & Guidance

- Software-generated forces that constrain (forbidden-region) or guide (path-following) tool motion. Key challenge: superimposing guidance + environment forces on single haptic channel. [Bowyer 2014, Kundrat 2019]

Sensorless Force Estimation

- Deep-learning-based inverse dynamics on dVRK: only 5–10% accuracy drop vs. sensor-based feedback for palpation tasks. [Yilmaz 2024]

Limitations

- **Closed platforms**
  → limits algorithm customization

Research Gap & Our Contribution

Research Gap

No systematic study of the Haply Inverse3 as a master-side haptic interface for da Vinci teleoperation with active haptic guidance feedback.

Our Contribution

1. Interface Haply Inverse3 with da Vinci as haptic master device
2. Implement haptic guidance via force feedback during hot wire task
3. Evaluate effect on operator precision in controlled user study

Why is this relevant? The Haply Inverse3 offers 3-DoF force feedback at 4 kHz with sub-millimeter resolution in a compact, low-inertia parallel-kinematic package – enabling high-fidelity haptic guidance that is not possible with the native da Vinci.

Theory of Shared Control

Shared Control

Our Goal

The Technical Committee on Shared Control is a group formed of international specialists who envision a world in which human-machine interaction is safer, more intuitive, more comfortable and more robust to differences in environment and

TC Leadership

Yuichi Saito

TC Co-Chair

University of Tsukuba, Japan

Email Yuichi

Balint Varga

TC Co-Chair

Karlsruhe Institute of Technology, Germany

Email Balint

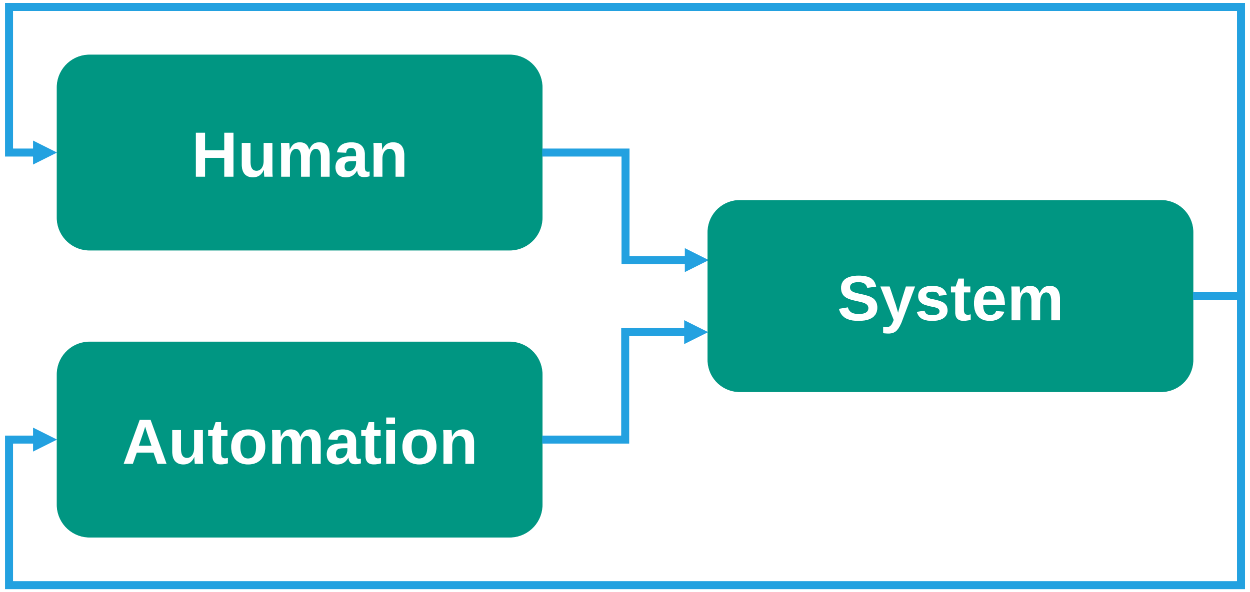
[1] A. M. Annaswamy, K. H. Johansson and G. Pappas, "Control for Societal-Scale Challenges: Road Map 2030, Chapter **Cyber-Physical-Human Systems**" in *IEEE Control Systems Magazine*, vol. 44, no. 3, pp. 30-32, June 2024, doi: 10.1109/MCS

Vision of Shared Control

Shared control: An approach in which control is distributed between two or more parties, allowing them to collaborate and make decisions together.

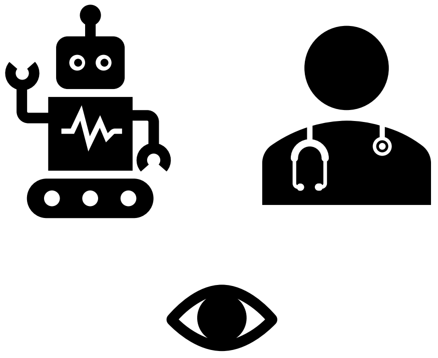
The goal is **cooperative**, **non-conflicting** behavior

- Mutual Benefits
  - **Human**:
    - Domain knowledge and context-aware decisions
  - **Machine**:
    - Repetitive tasks, precision, and enforcing safety limits.
- Examples of shared control systems:
  - Driver-assistance systems in cars (e.g., lane keeping)
  - Shared-control wheelchairs



Vision of Shared Control

Surgeons and robotic systems
mutually conduct operations to reach
better patient outcome



Possible Future Research

Shortening the learning phases of **young surgeons**

Supporting tired surgeons to **reduce medical errors**

Advancing the field of **teleoperation**

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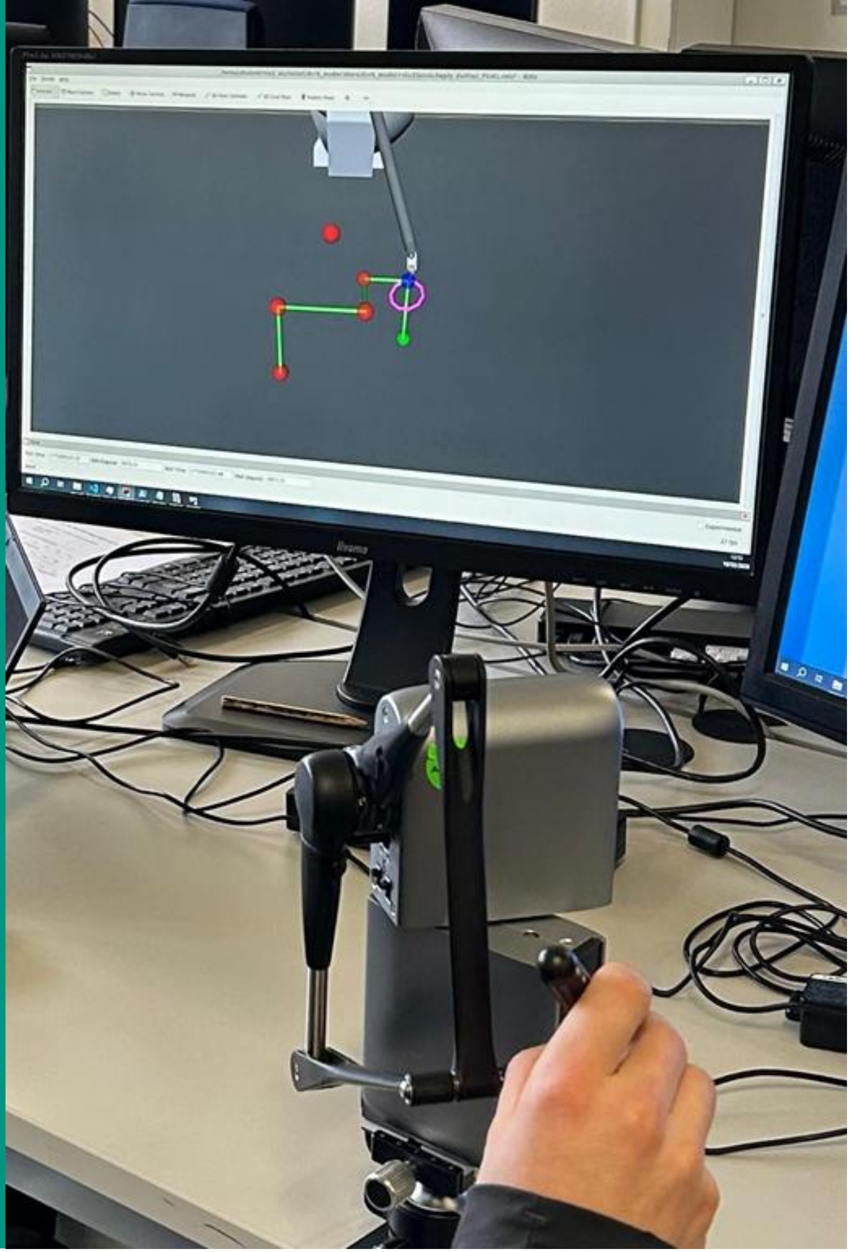
Haply Inverse3 and da Vinci



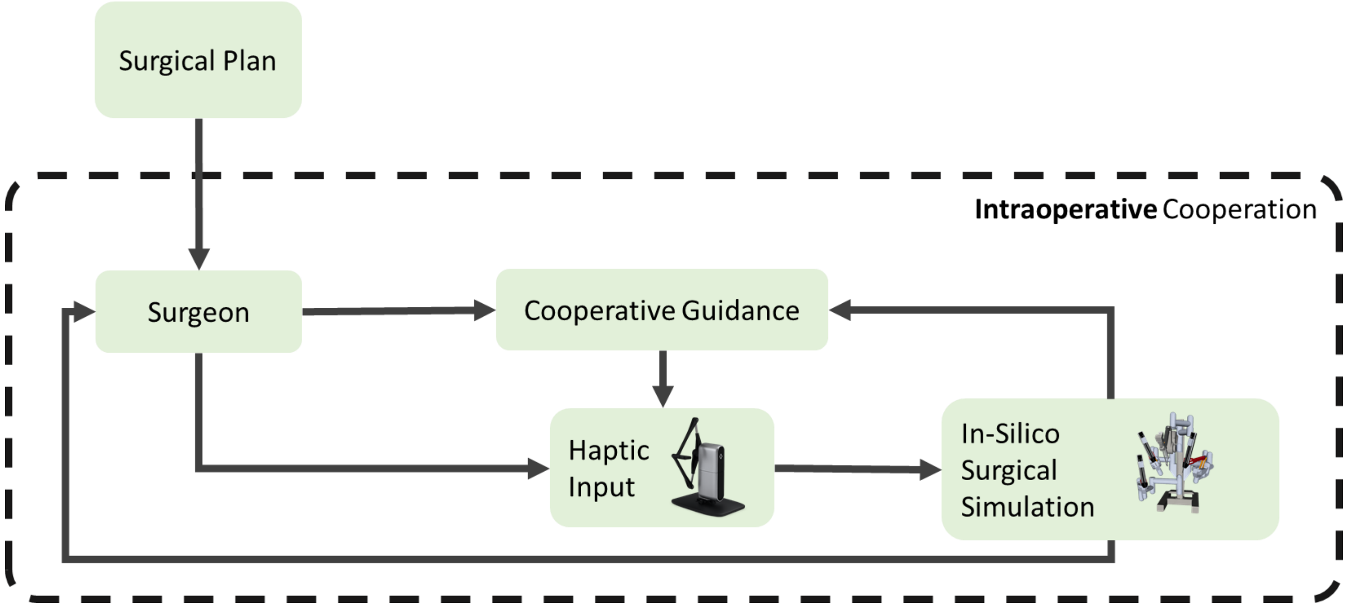
Shared Control System
Development with Haply Inverse3 and da Vinci

First Time binding of Inverse3 and da Vince: We developed novel ROS2 libraries for Inverse enabling the communication

- High Precision input device
  - **3 DoF Feedback, forces, no torques**
- Modular System:
  - a) Pure Simulation, b) Human-in-the-loop Experiments and c) Real Experiments

The goal is **cooperative**, **non-conflicting** behavior

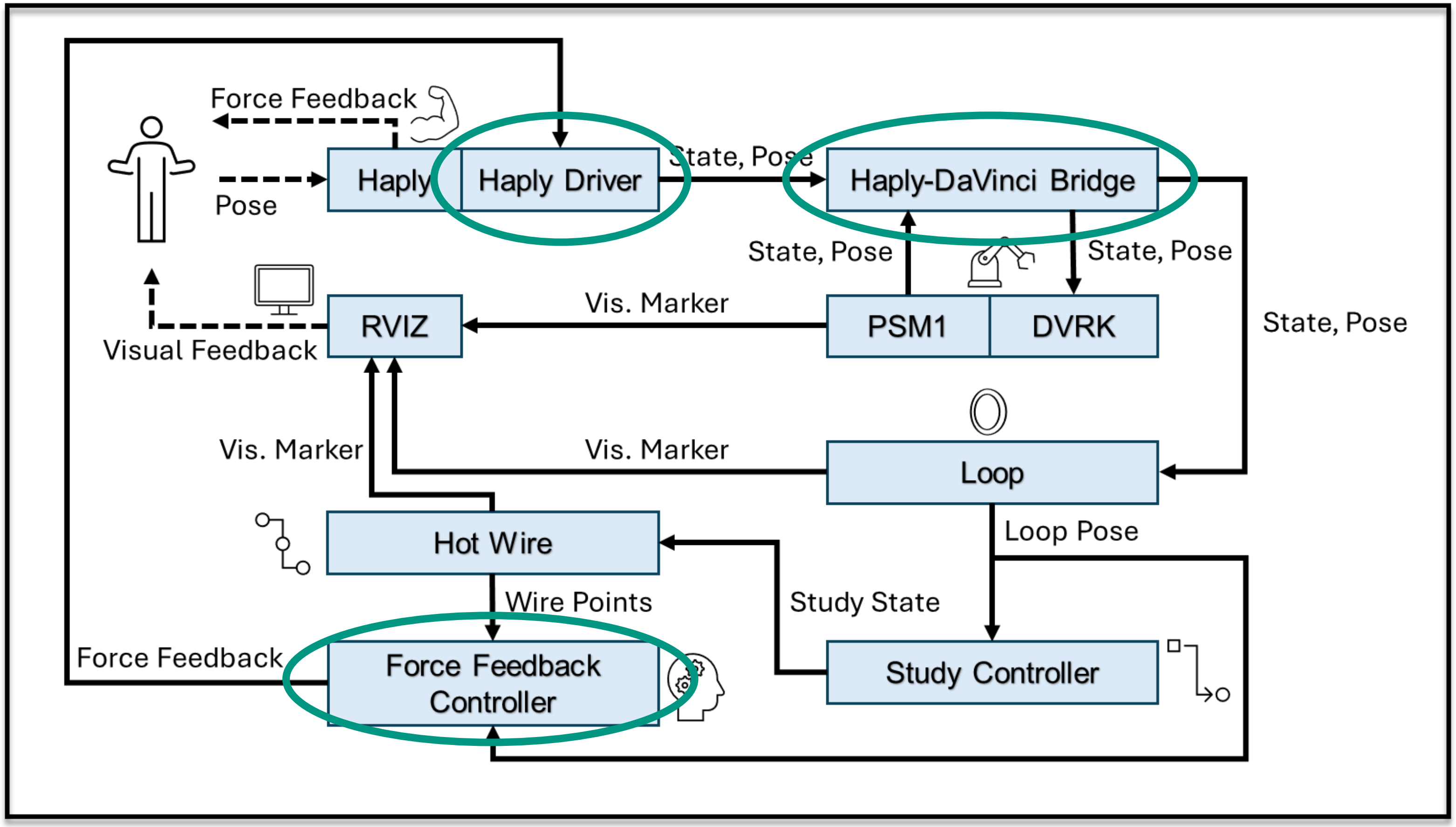
- Shared Control (Cooperative Guidance)
  - helps **surgeons** if they are
    - **Unexperienced**
    - Experienced, but **exhausted**
  - supports training



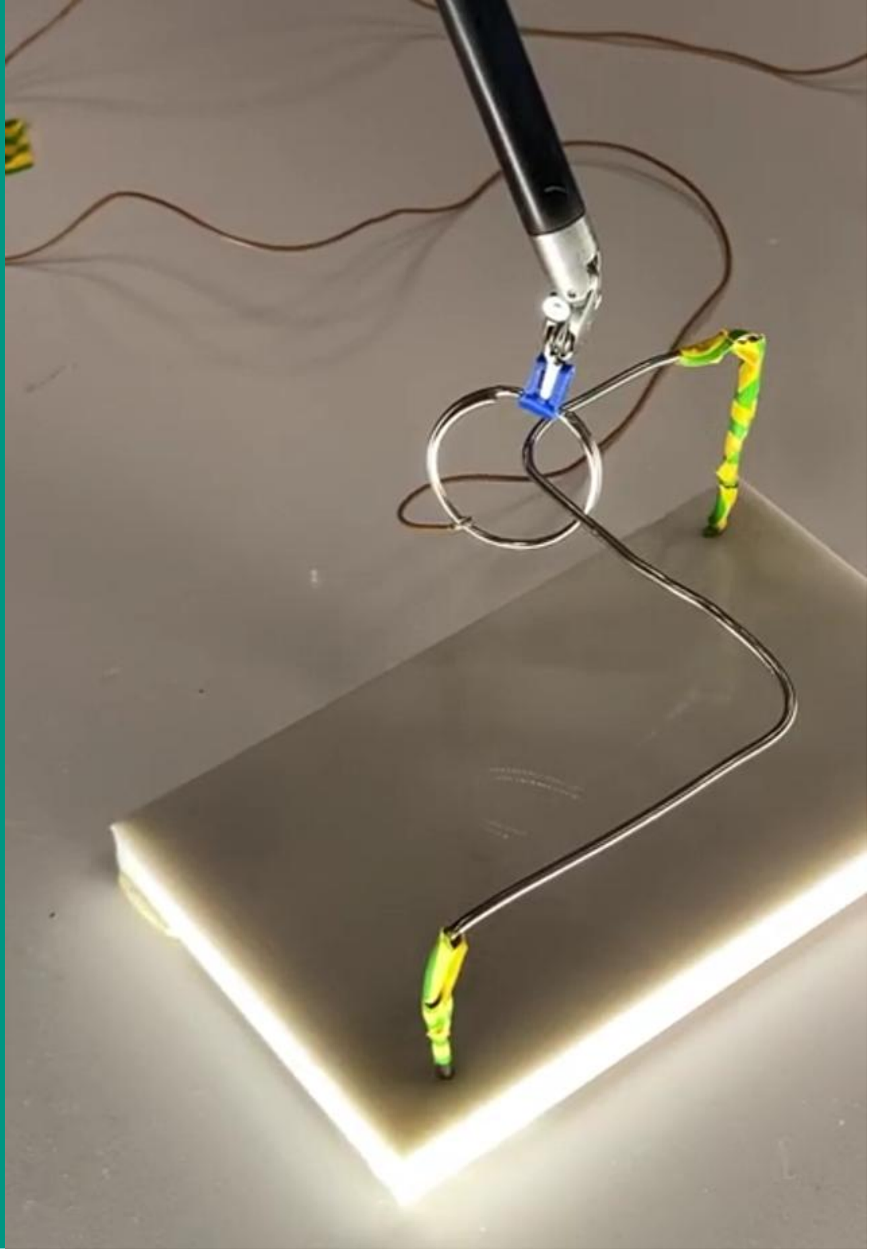
System Architecture

- **Software Architecture**:
  - Novel Driver for Haply Inverse3 as a ROS2 package

- **Input-Mapping**:
  - **Pose mapping**
  - **Reference and transfer**: On startup or during clutching, a Haply reference pose is stored, and the difference to the current pose is scaled and mapped to the daVinci joint angles
  - **Controls**: Button B resets the reference pose, and Button A toggles the gripper open or closed.



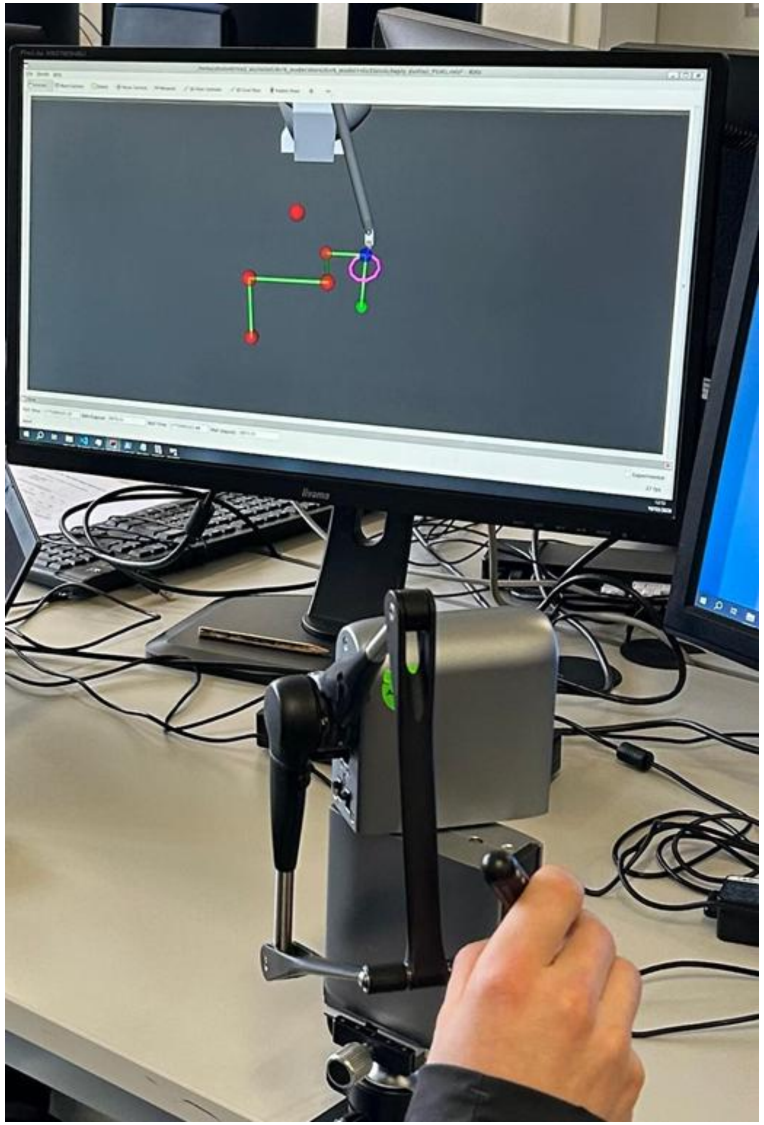
Feasibility Teleoperation Study at KIT and OE



Feasibility Study – Design

- **Participants**
  - 17 subjects (7 female, 10 male), ages 25–65
  - Varying prior teleoperation experience

- **Protocol**
  - 5 min training per mode (15 min total)
  - Mode order counterbalanced to control for learning effects
  - Visual contact feedback via wire color change



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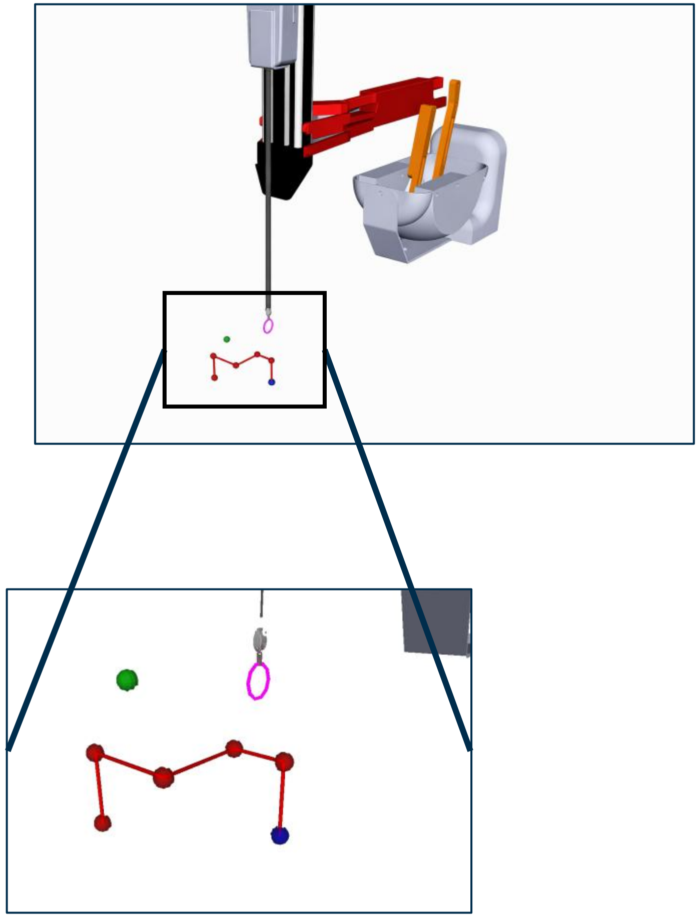
- **Three Feedback Modes**
  - **Mode 0**: No force feedback (baseline)
  - **Mode 1**: Linearly increasing FF (max ~1 N)
  - **Mode 2**: Step-wise increasing FF – low at distance, steep rise near contact (max ~1 N)
- **Note:** Ring can un-thread from wire; no FF is given while un-threaded. Subjects must re-thread manually.

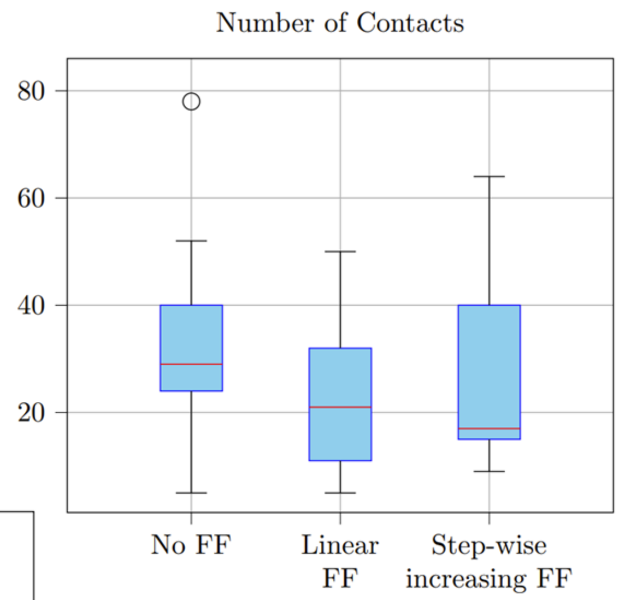


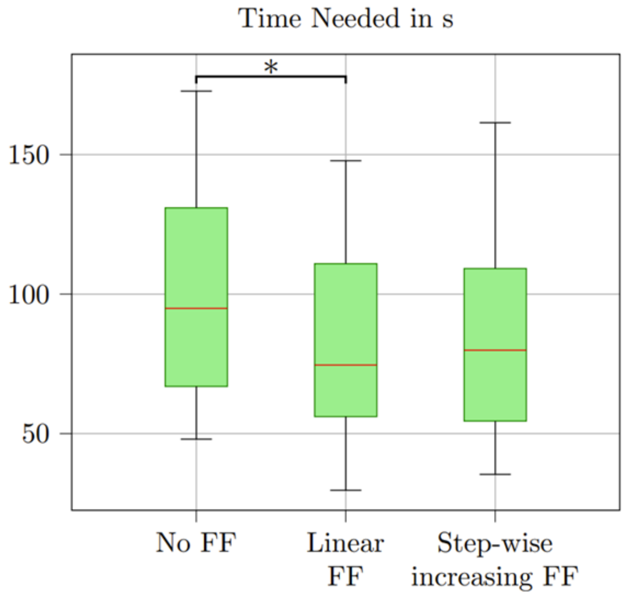
Feasibility Study – Results

- **Number of Contacts**
  – Linear FF Mode performs best (median)
  – Step-wise FF feels subtle → more cautious behavior → fewer contacts than no FF Mode

- **Task Completion Time**
  – Linear FF Mode is fastest (median)
  – Early, strong FF → higher confidence → faster movement, but more contacts

- **Statistical Analysis**
  – Pair t-test
  a. Time: statistical better FF mode
  b. Contact: No statistical difference





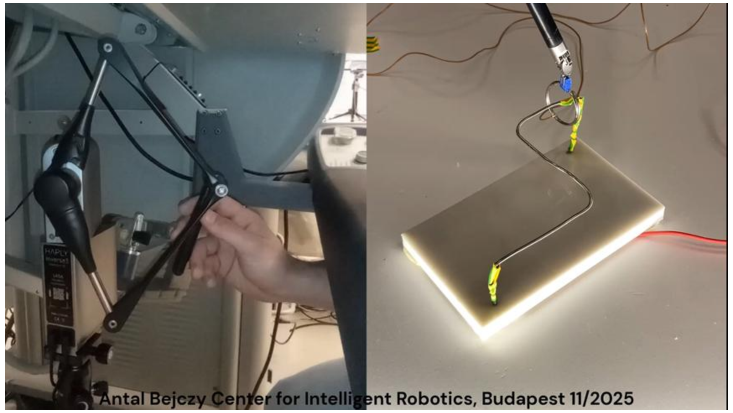
Feasibility Study – Observations

- **High Variance Across All Modes**
  – Reflects heterogeneous prior experience (drone/model aircraft operators performed notably better)
  – Clear performance gap between experienced (drone/model flight) and inexperienced participants

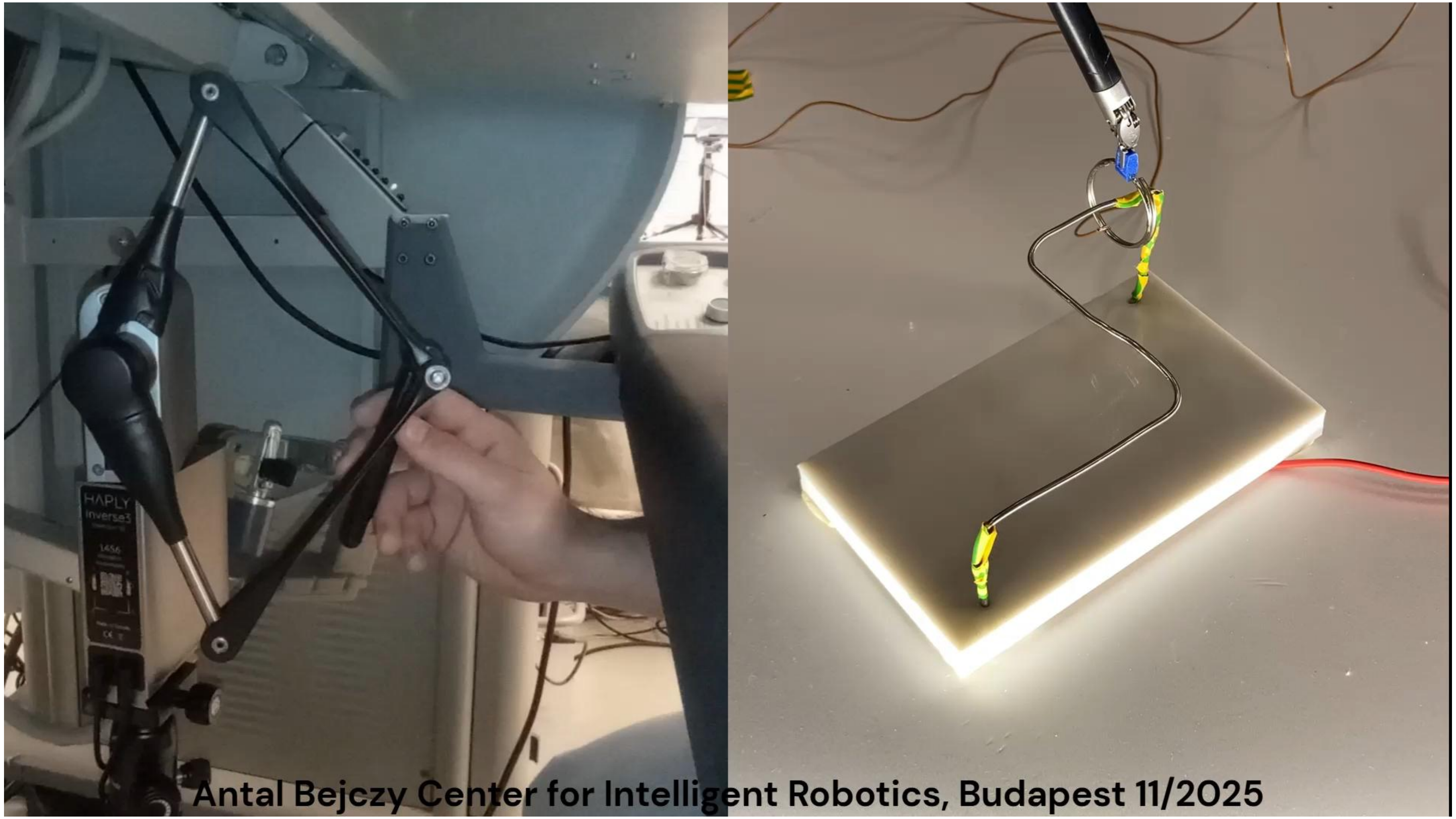
- **Key Observations**
  – Limited depth perception increased task difficulty, especially for novices
  – Strong learning effects due to high task difficulty

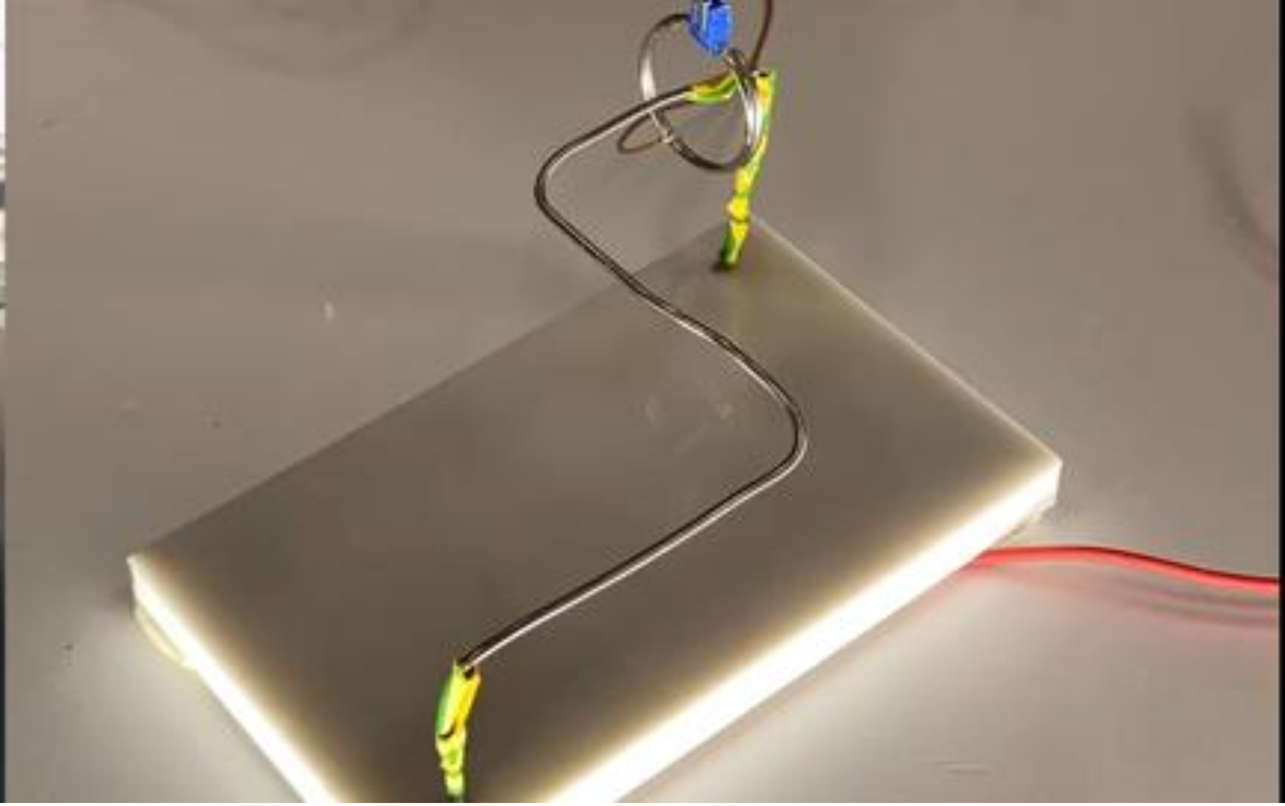
- **Proposed Improvements**
  – VR headset for improved depth perception
  – User-adjustable FF intensity
  – On-the-fly motion scaling & singularity avoidance
  – Ring-shaped buttons on VerseGrip for easier grip-independent access

- Real-world setting
  – Thank to the modular structure plug'n'play



Real-World Setting – Results





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Thank you!

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