Master Thesis Presentation

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TU Delft

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CERN

Visio-Verbal Teleimpedance: A Gaze and Speech-Driven VLM Interface for Human-Centric Semi-Autonomous Robot Stiffness Control

Revision date: 23.3.2025

All slides and images were created by Henk Jekel (unless indicated otherwise).

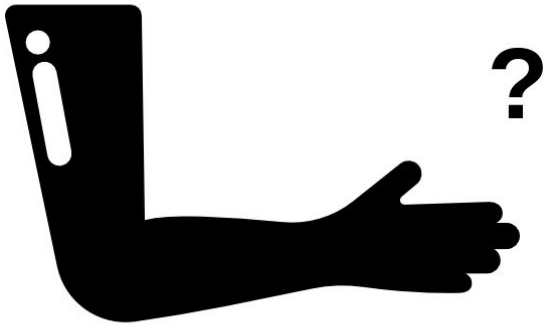
Outline

After this presentation, the should be able to:

1. **Understand** teleimpedance
2. **Compare** existing teleimpedance interfaces to the proposed *visio-verbal* approach
3. **Understand** the hardware and software architecture of the *visio-verbal* interface
4. **Understand** prompting a vision language model
5. **Understand** the prompt engineering experiment and **reflect** on the results and finally the **voice only** interface results sofar

1 Impedance control - Relevance

- Humans regulate arm impedance to simplify and improve the control of interaction with **unknown** and unpredictable environments.

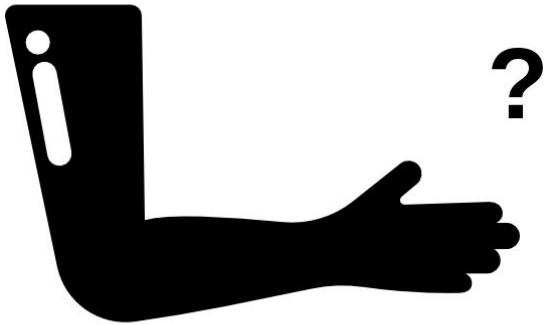


1 Impedance control - Relevance

- Humans regulate arm impedance to simplify and improve the control of interaction with unknown and **unpredictable** environments.

1 Impedance control - Relevance

- Humans regulate arm impedance to simplify and improve the control of interaction depending on the **task requirements**.



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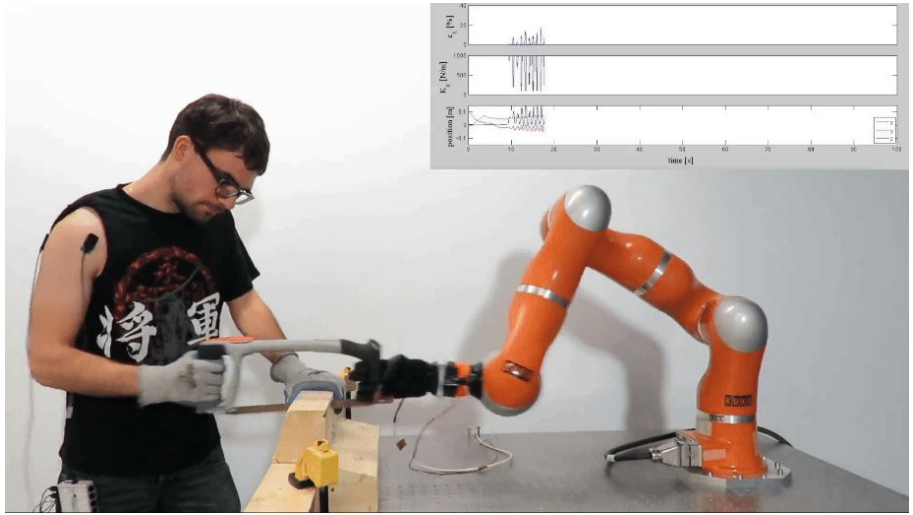
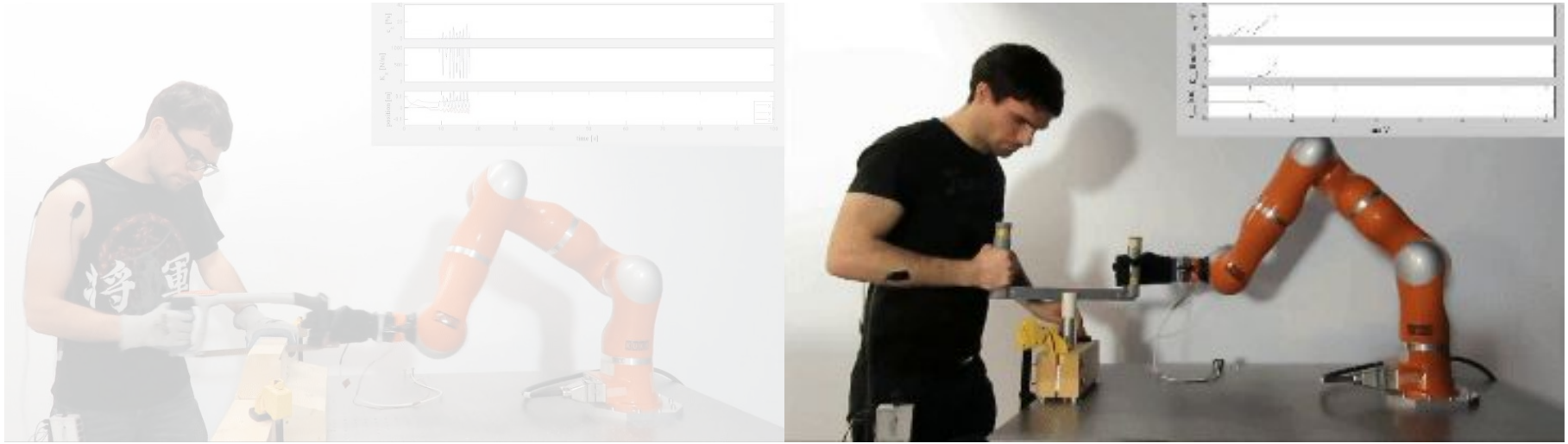
1 Impedance control - Relevance



- 1) Peternel L, Tsagarakis N, Ajoudani A (2017), A human–robot co-manipulation approach based on human sensorimotor information. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 25(7):811-22.

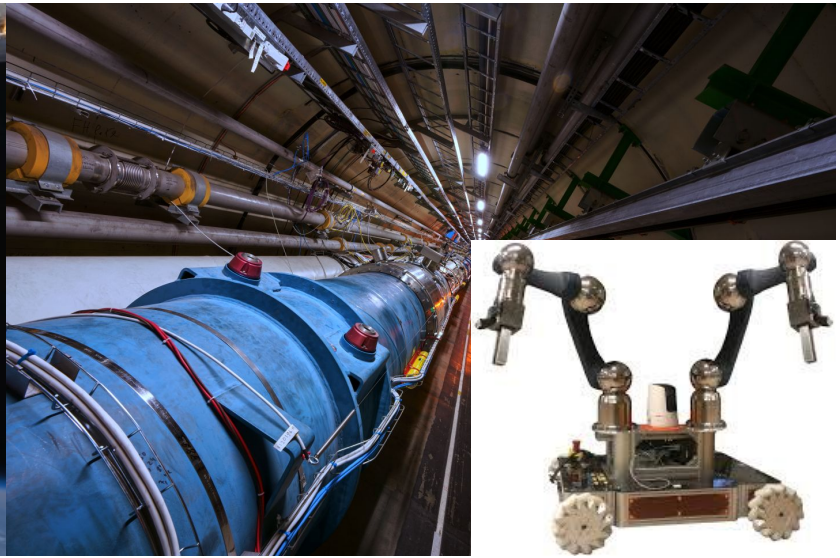
1 Impedance control - Relevance



- 1) Peternel L, Tsagarakis N, Ajoudani A (2017), A human–robot co-manipulation approach based on human sensorimotor information. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 25(7):811-22.

1 Teleoperation - Relevance

International Space Station: DEXTRE
(Image: NASA)

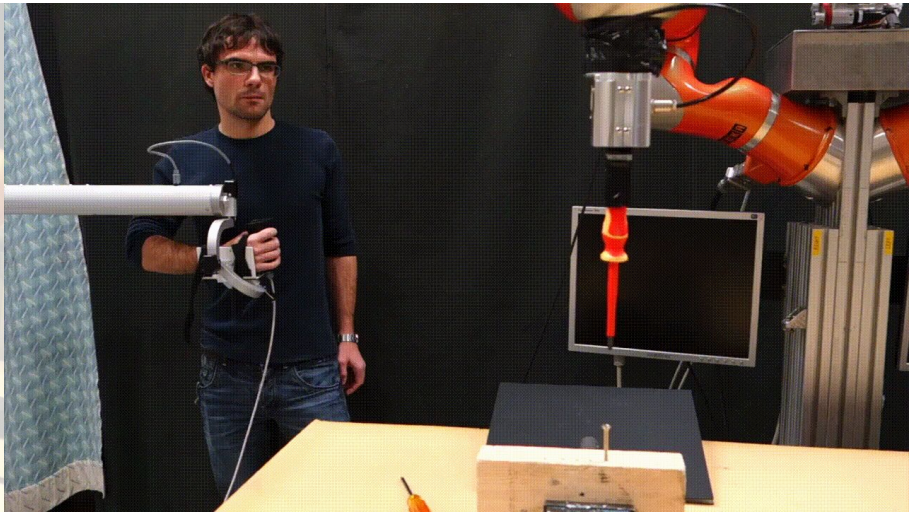


Large Hadron Collider: CERNbot
(Image: NASA)

1 Relevance - Tele-Impedance

2) Peternel, L., Petrič, T., & Babič, J. (2018). Robotic assembly solution by human-in-the-loop teaching method based on real-time stiffness modulation. *Autonomous Robots*, *42*(1), 1-17.

1 Relevance - Tele-Impedance



2) Peternel, L., Petrič, T., & Babič, J. (2018). Robotic assembly solution by human-in-the-loop teaching method based on real-time stiffness modulation. *Autonomous Robots*, *42*(1), 1-17.

2. Existing Methods:

2. Existing Methods: Manual Approaches

- **Direct human input**

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Manual Approaches

Manual ⟵ ⟶ Autonomous

MUSCLE-BASED

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Manual Approaches

Manual ⟵ ⟶ Autonomous

MUSCLE-BASED

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2. Existing Methods: Manual Approaches

Manual ⟵ ⟶ Autonomous

MUSCLE-BASED

- **Coupling Effect**
- **Complex Setup**

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Manual Approaches

Manual ⟵ ⟶ Autonomous

MUSCLE-BASED

FORCE GRIP-BASED

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Manual Approaches

Manual ⟷ Autonomous

MUSCLE-BASED

FORCE GRIP-BASED

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Manual Approaches

MUSCLE-BASED

FORCE GRIP-BASED

- **Coupling Effect**
- **Limited Control**

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Manual Approaches

MUSCLE-BASED

FORCE GRIP-BASED

EXTERNAL DEVICE

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2. Existing Methods: Manual Approaches

Manual ⟵ ⟶ Autonomous

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FORCE GRIP-BASED

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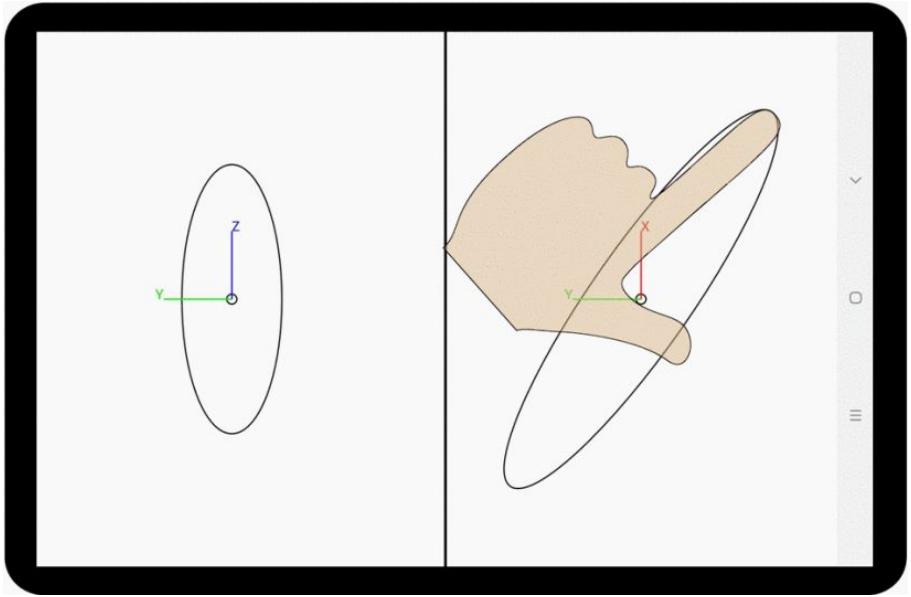
2. Existing Methods: Manual Approaches

Manual ⟵ ⟶ Autonomous

MUSCLE-BASED

FORCE GRIP-BASED

EXTERNAL DEVICE



4) Peternel, L., & Ajoudani, A. (2020). Independently commanding size, shape and orientation of robot endpoint stiffness in tele-impedance by virtual ellipsoid interface. *IEEE Transactions on Haptics*, 13(4), 699–704.

2. Existing Methods: Manual Approaches

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

- **Limited Control**
- **Visual Attention**

3) Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.

2. Existing Methods: Automated Approaches

MUSCLE-BASED

FORCE GRIP-BASED

EXTERNAL DEVICE

2. Existing Methods: Automated Approaches

MUSCLE-BASED

FORCE GRIP-BASED

EXTERNAL DEVICE

Integrated Torque Sensors

2. Existing Methods: Automated Approaches

Manual → Autonomous

MUSCLE-BASED

FORCE GRIP-BASED

EXTERNAL DEVICE

Integrated Torque Sensors

5) Michel, Y., Rahal, R., Pacchierotti, C., Robuffo Giordano, P., & Lee, D. (2022). Bilateral teleoperation with adaptive impedance control for contact tasks. *IEEE Transactions on Robotics*, 38(6), 3647–3666.

2. Existing Methods: Automated Approaches

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Integrated Torque Sensors

- **No direct control**
- **Not able to set stiffness before interaction**

2. Existing Methods: Automated Approaches

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Integrated Torque Sensors
Vision-based

2. Existing Methods: Automated Approaches

Manual ⟵ ⟶ Autonomous

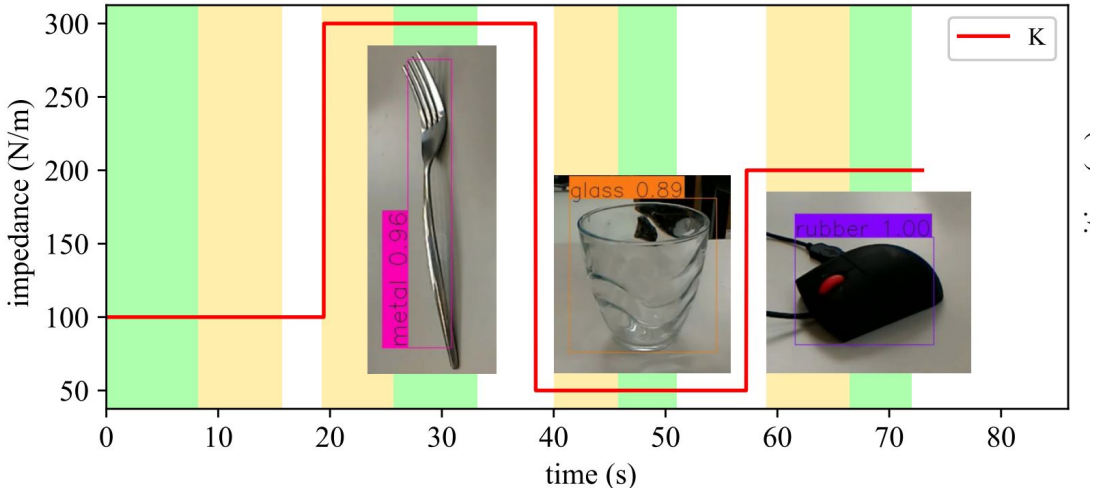
MUSCLE-BASED

FORCE GRIP-BASED

EXTERNAL DEVICE

Integrated Torque Sensors

Vision-based



6) Huang, Y.-C., Abbink, D. A., & Peternel, L. (2021). A semi-autonomous tele-impedance method based on vision and voice interfaces. IEEE Transactions on Haptics, 14(4), 845–856.

2. Existing Methods: Automated Approaches

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Integrated Torque Sensors
Vision-based

- **No direct control**
- **Expensive hardware**

2. Existing Methods: Automated Approaches

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Visio-Verbal Interface

Integrated Torque Sensors
Vision-based

3. Visio-Verbal Interface: Requirements

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Visio-Verbal Interface

Integrated Torque Sensors
Vision-based

3. Visio-Verbal Interface: Requirements

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Visio-Verbal Interface

Integrated Torque Sensors
Vision-based

- **R1: Combine eye-tracking with verbal interaction for stiffness matrix generation.**

3. Visio-Verbal Interface: Requirements

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Visio-Verbal Interface

Integrated Torque Sensors
Vision-based

- **R1: Combine eye-tracking with verbal interaction for stiffness matrix generation.**
- **R2: Enable the operator to control the full 3D translational endpoint stiffness.**

3. Visio-Verbal Interface: Requirements

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Visio-Verbal Interface

Integrated Torque Sensors
Vision-based

- **R1: Combine eye-tracking with verbal interaction for stiffness matrix generation.**
- **R2: Enable the operator to control the full 3D translational endpoint stiffness.**
- **R3: Allow stiffness adjustments without diverting visual attention from position tracking.**

3. Visio-Verbal Interface: Requirements

MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

Visio-Verbal Interface

Integrated Torque Sensors
Vision-based

- **R1: Combine eye-tracking with verbal interaction for stiffness matrix generation.**
- **R2: Enable the operator to control the full 3D translational endpoint stiffness.**
- **R3: Allow stiffness adjustments without diverting visual attention from position tracking.**
- **R4: Minimize setup and calibration procedures.**

3. Visio-Verbal Interface: Requirements

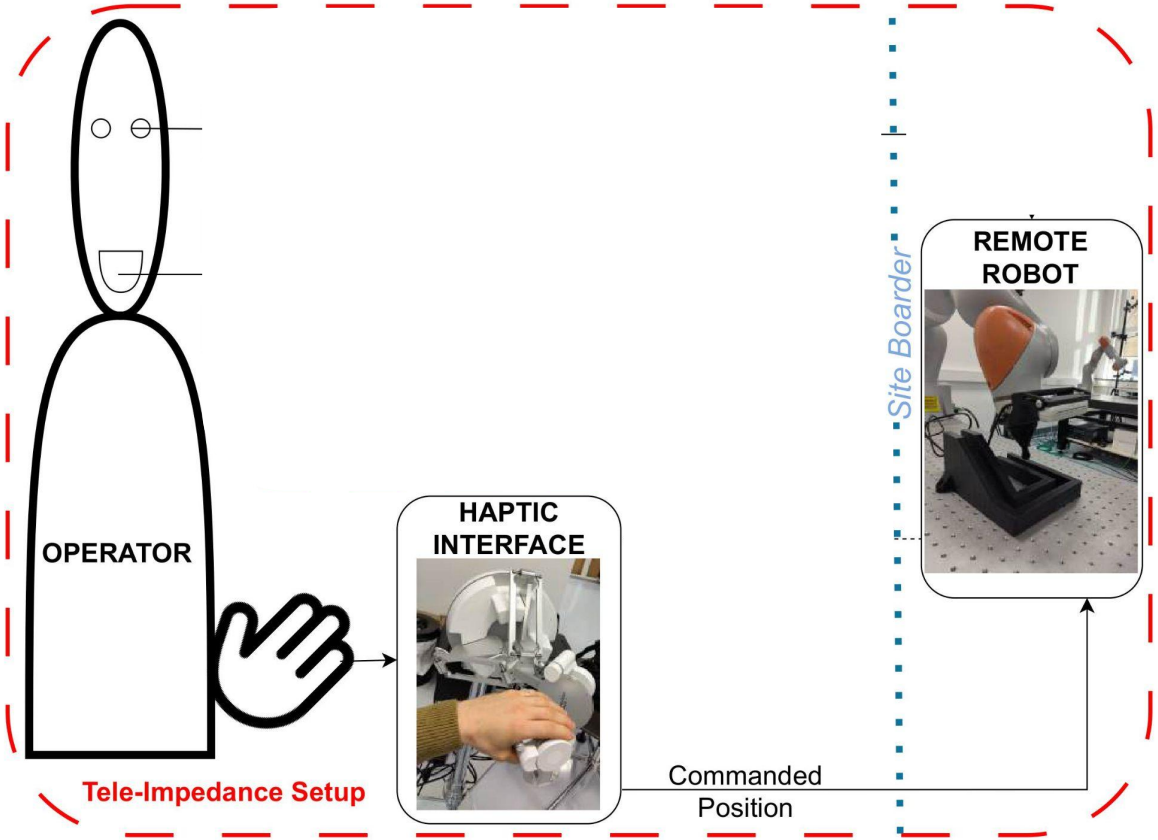
MUSCLE-BASED
FORCE GRIP-BASED
EXTERNAL DEVICE

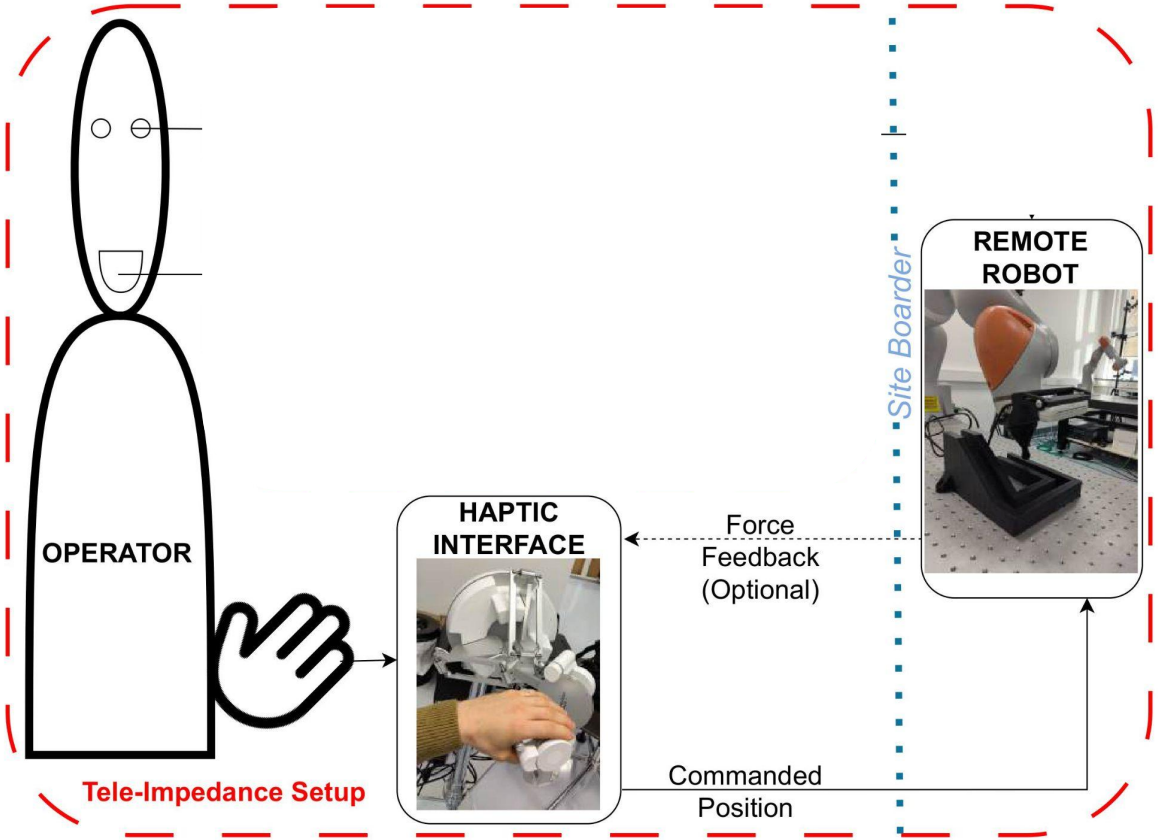
Visio-Verbal Interface

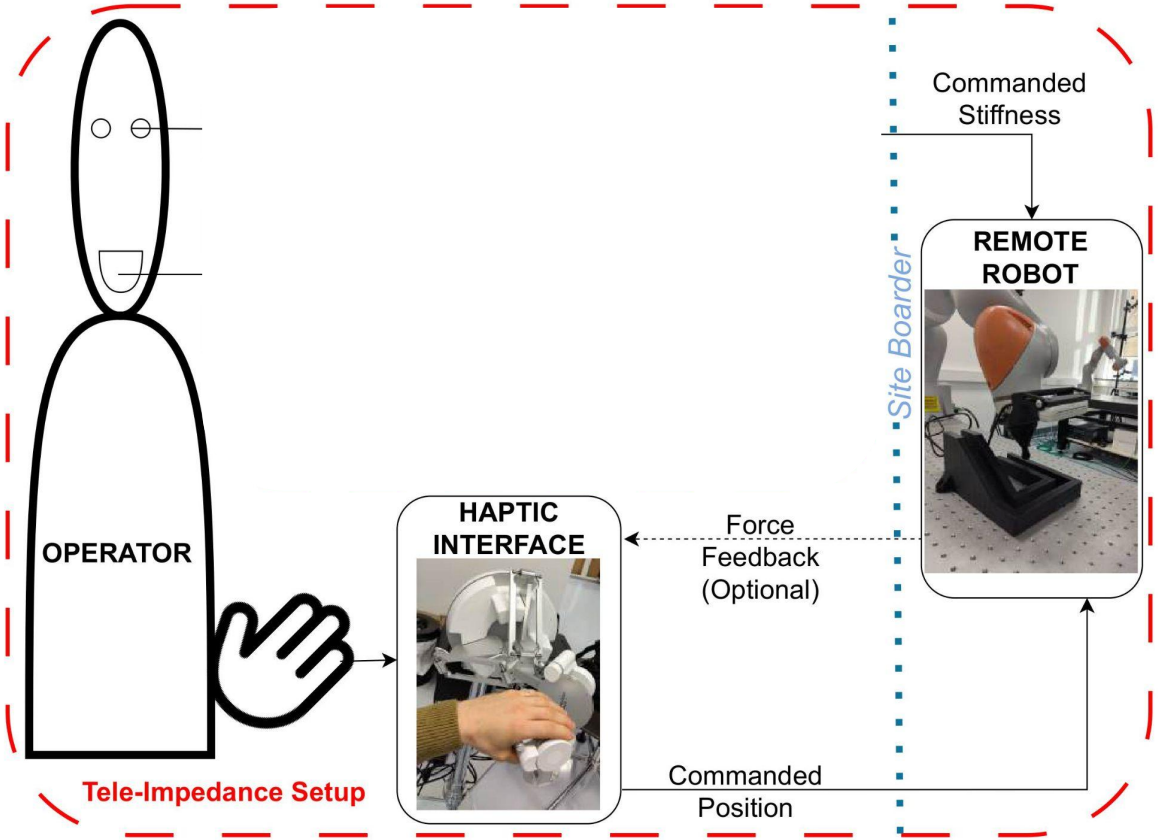
Integrated Torque Sensors
Vision-based

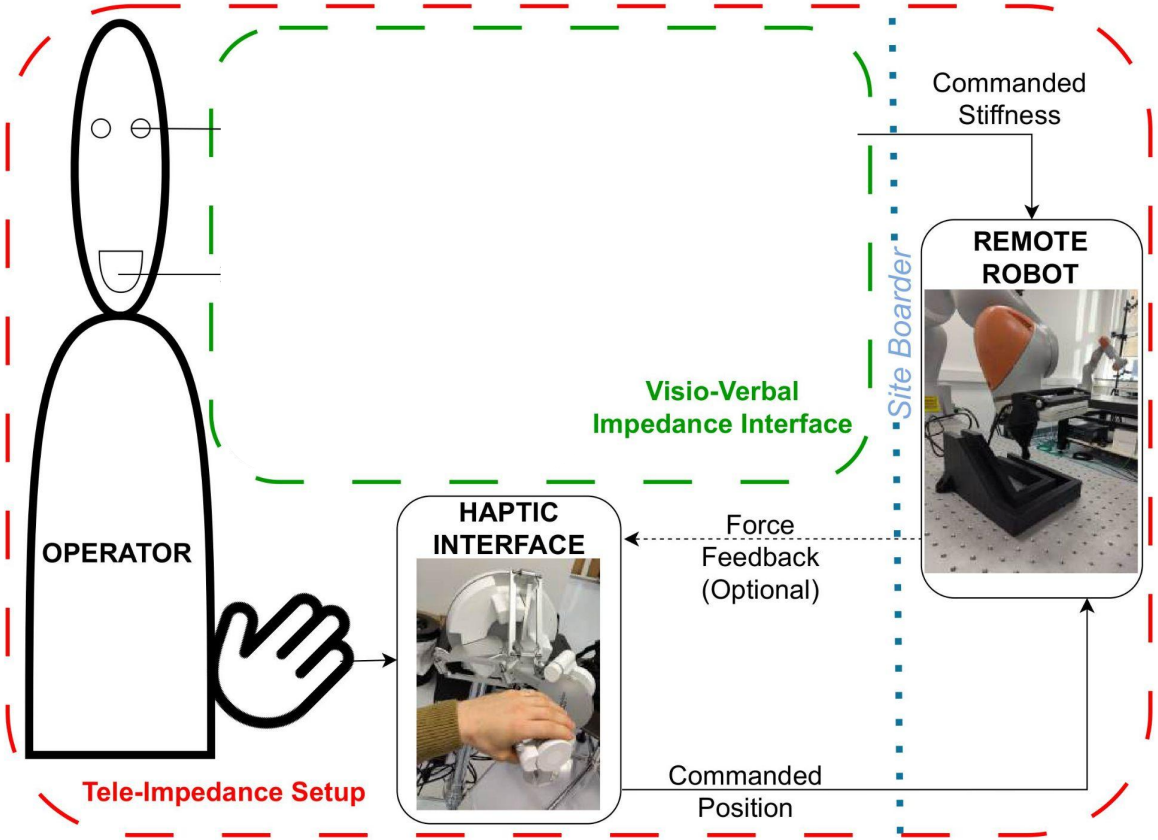
- **R1: Combine eye-tracking with verbal interaction for stiffness matrix generation.**
- **R2: Enable the operator to control the full 3D translational endpoint stiffness.**
- **R3: Allow stiffness adjustments without diverting visual attention from position tracking.**
- **R4: Minimize setup and calibration procedures.**
- **R5: Prevent coupling between force feedback and commanded stiffness**

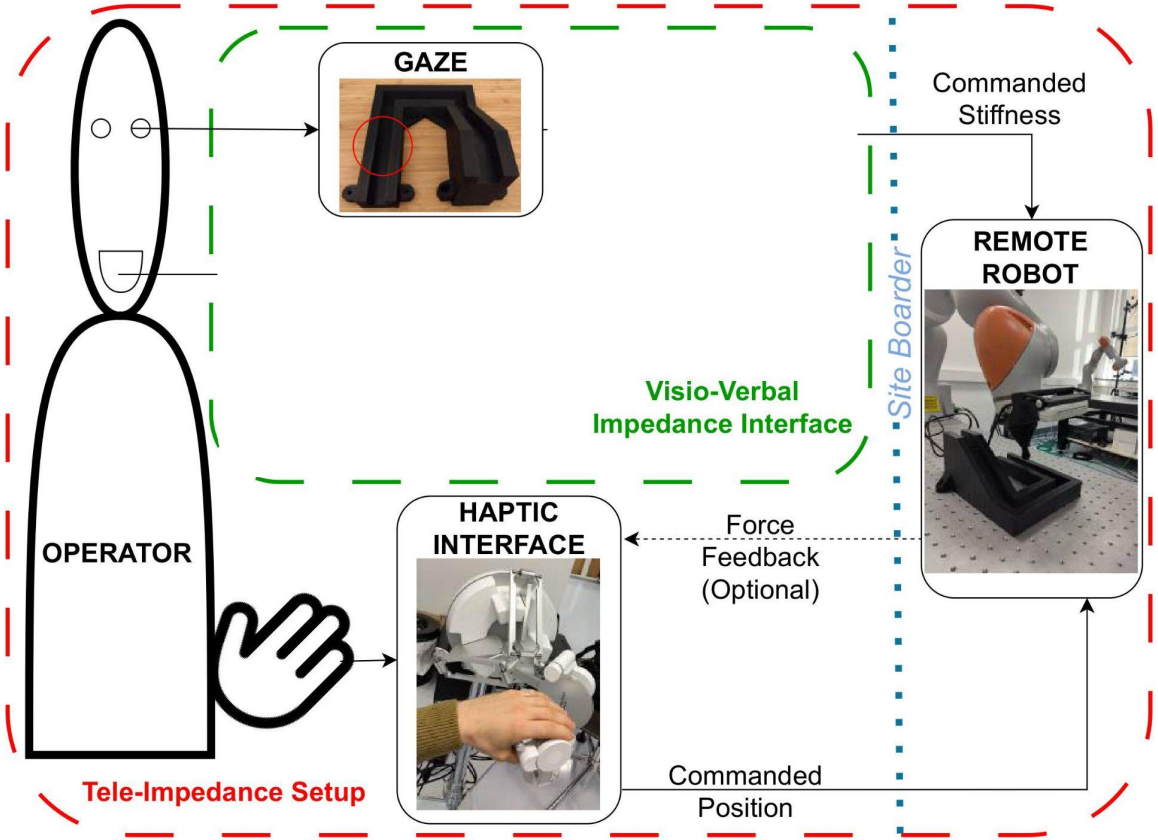
Tele-Impedance Setup

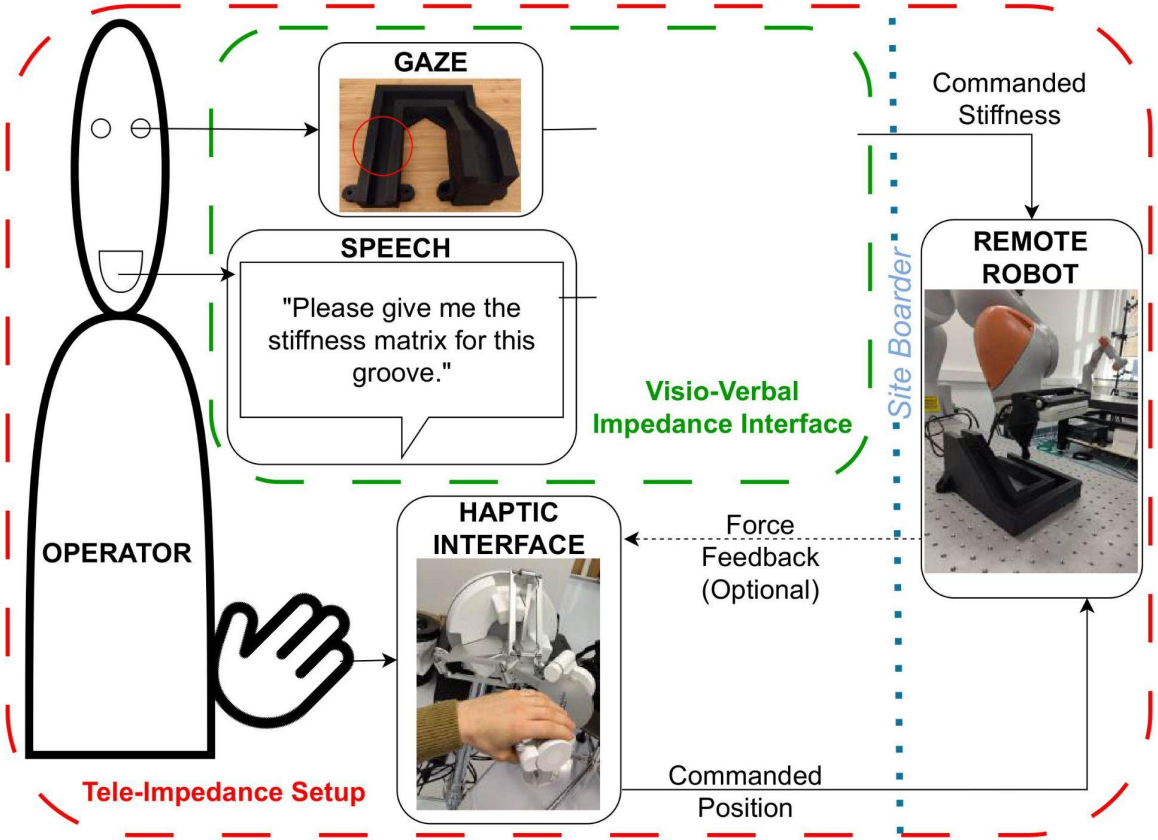

OPERATOR
HAPTIC INTERFACE
REMOTE ROBOT
Site Boarder
Tele-Impedance Setup
Commanded Position

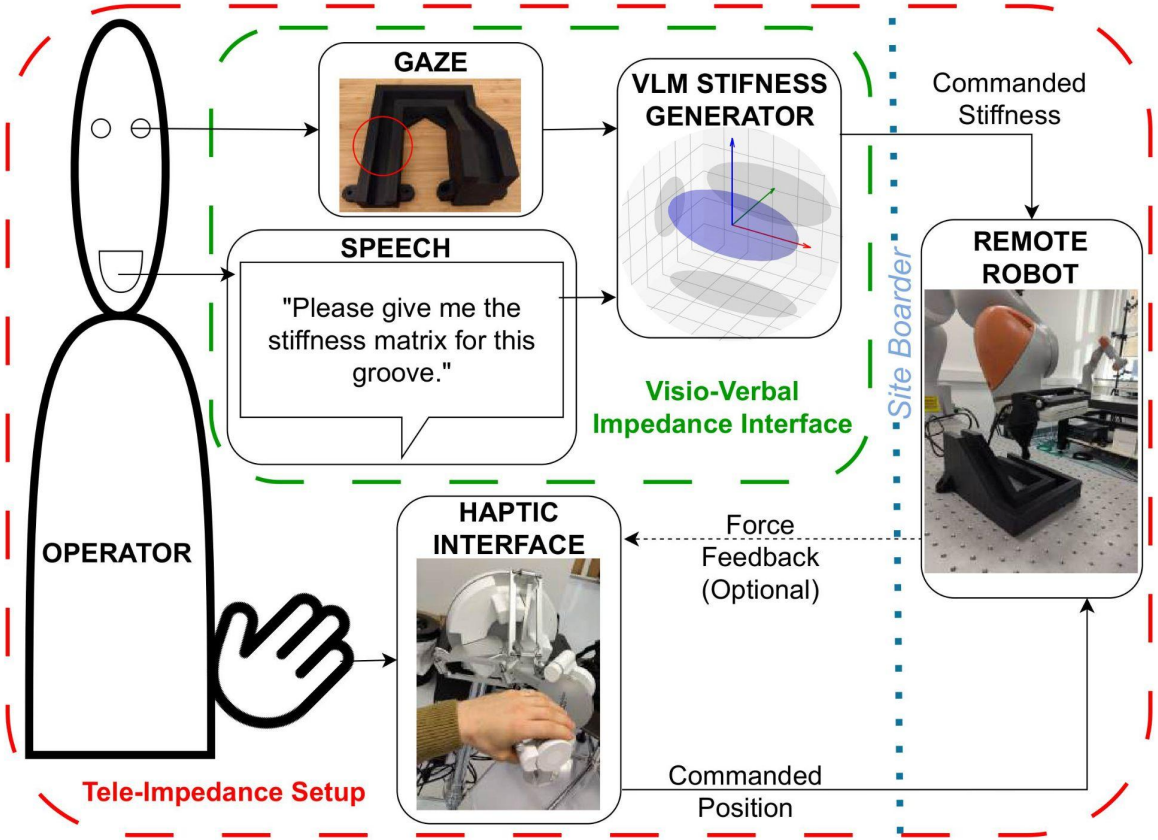

OPERATOR
Tele-Impedance Setup
HAPTIC INTERFACE
Force Feedback (Optional)
Commanded Position
Site Boarder
REMOTE ROBOT

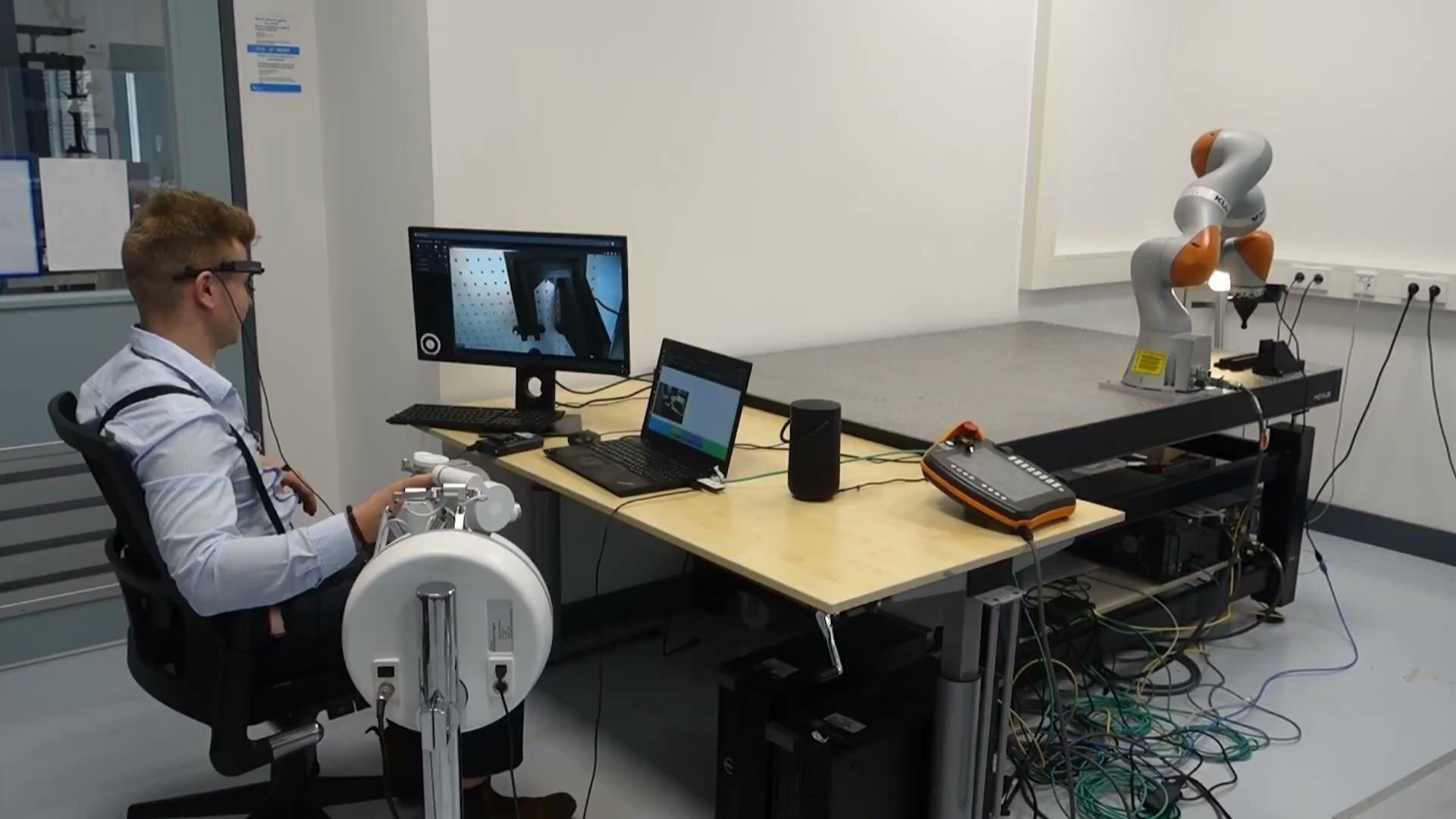

Commanded
Stiffness
REMOTE
ROBOT
Site Boarder
OPERATOR
HAPTIC
INTERFACE
Force
Feedback
(Optional)
Commanded
Position
Tele-Impedance Setup


Commanded
Stiffness
REMOTE
ROBOT
Site Boarder
Visio-Verbal
Impedance Interface
HAPTIC
INTERFACE
Force
Feedback
(Optional)
OPERATOR
Commanded
Position
Tele-Impedance Setup


GAZE
Commanded
Stiffness
REMOTE
ROBOT
Site Boarder
Visio-Verbal
Impedance Interface
HAPTIC
INTERFACE
Force
Feedback
(Optional)
OPERATOR
Tele-Impedance Setup
Commanded
Position


GAZE
SPEECH
"Please give me the stiffness matrix for this groove."
Visio-Verbal Impedance Interface
Commanded Stiffness
REMOTE ROBOT
Site Boarder
OPERATOR
HAPTIC INTERFACE
Force Feedback (Optional)
Commanded Position
Tele-Impedance Setup


GAZE
VLM STIFNESS GENERATOR
Commanded Stiffness
SPEECH
"Please give me the stiffness matrix for this groove."
Visio-Verbal Impedance Interface
Site Boarder
REMOTE ROBOT
OPERATOR
HAPTIC INTERFACE
Force Feedback (Optional)
Commanded Position
Tele-Impedance Setup



2. Existing Methods: Comparison

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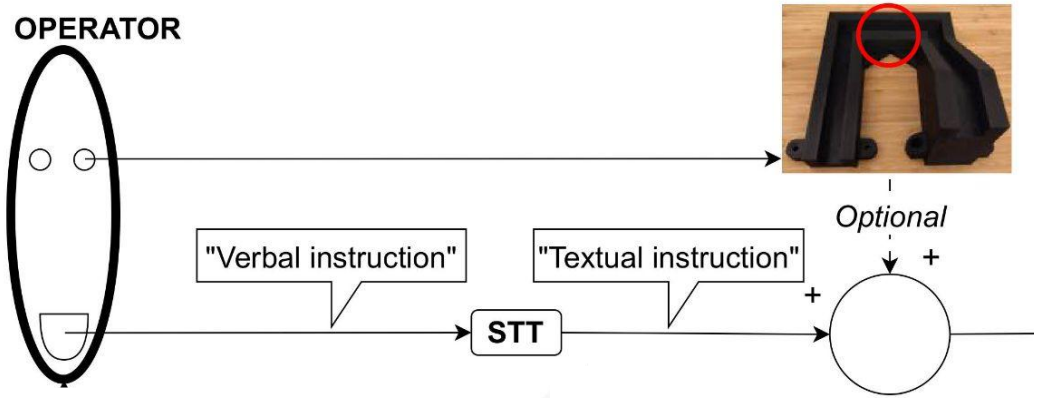

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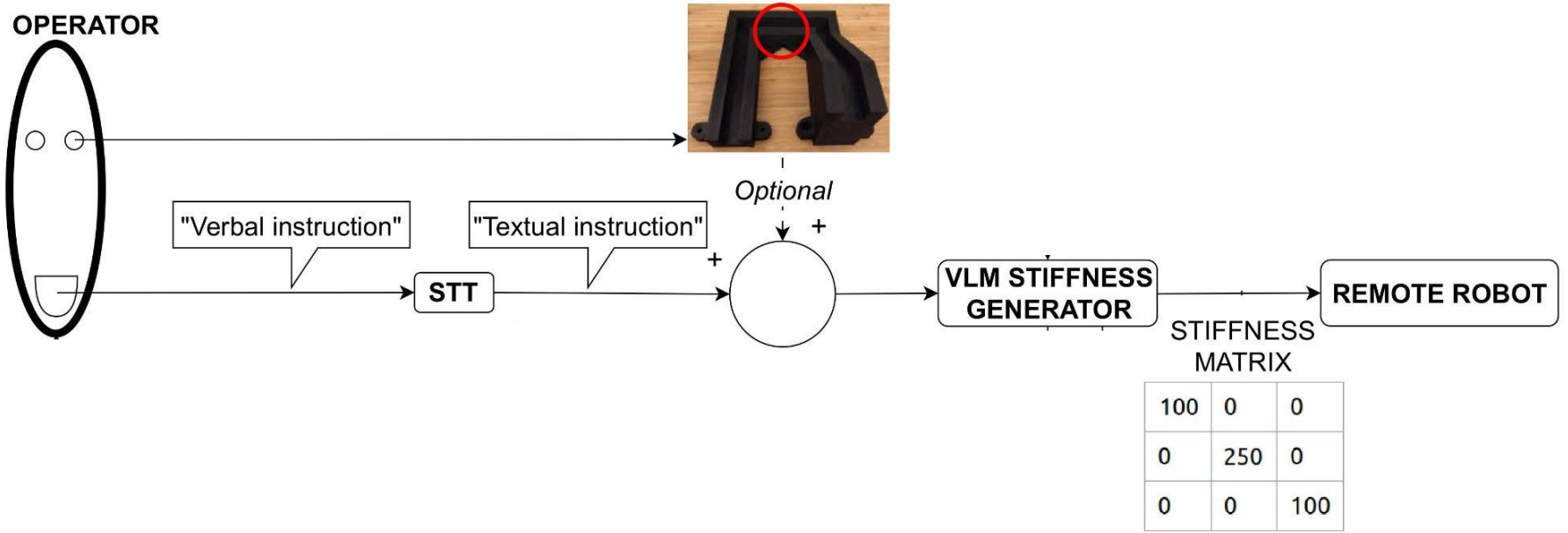

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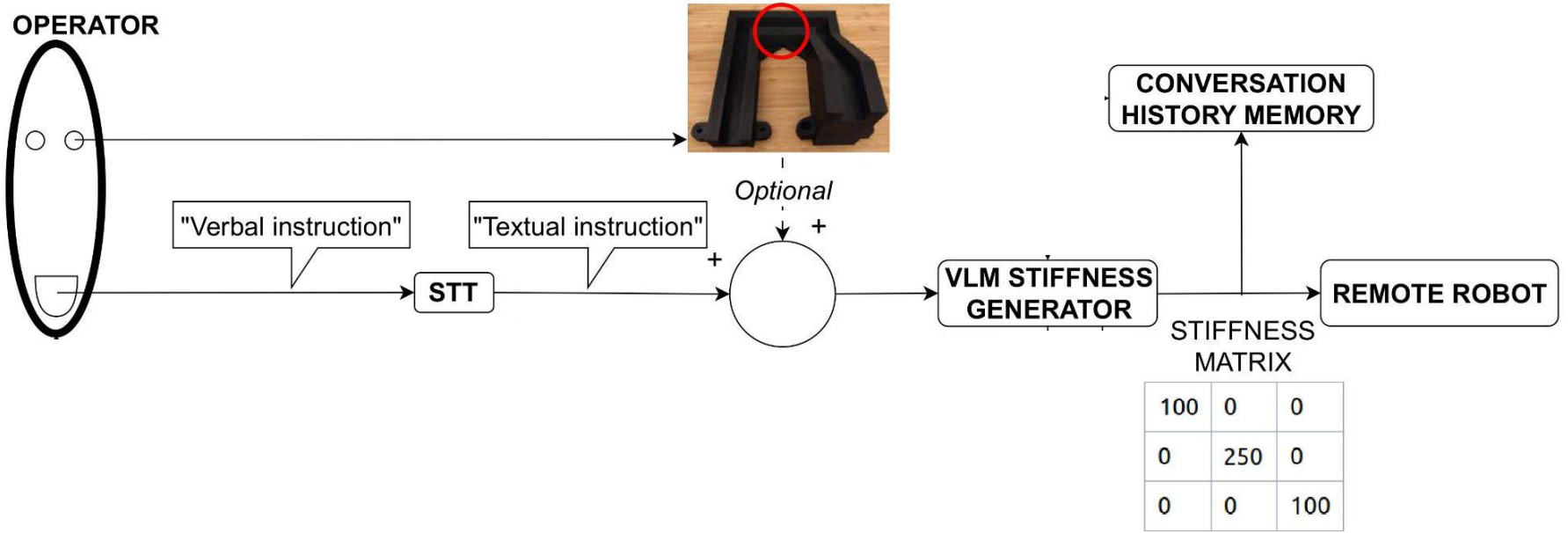

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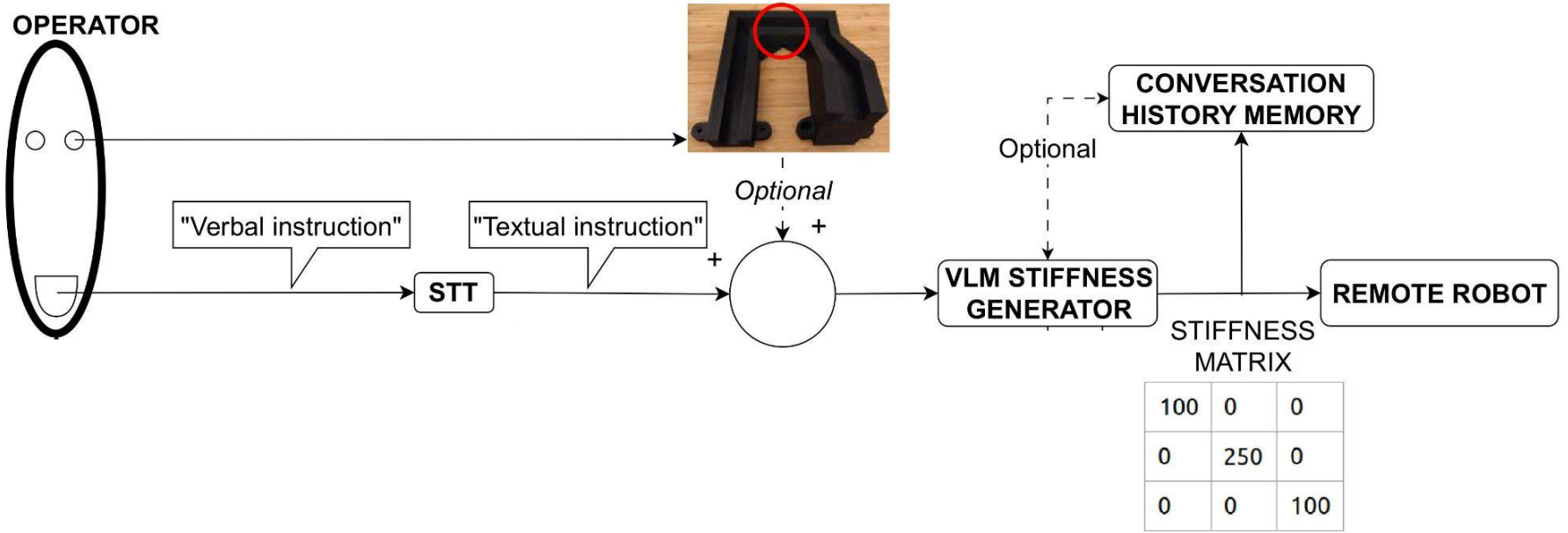

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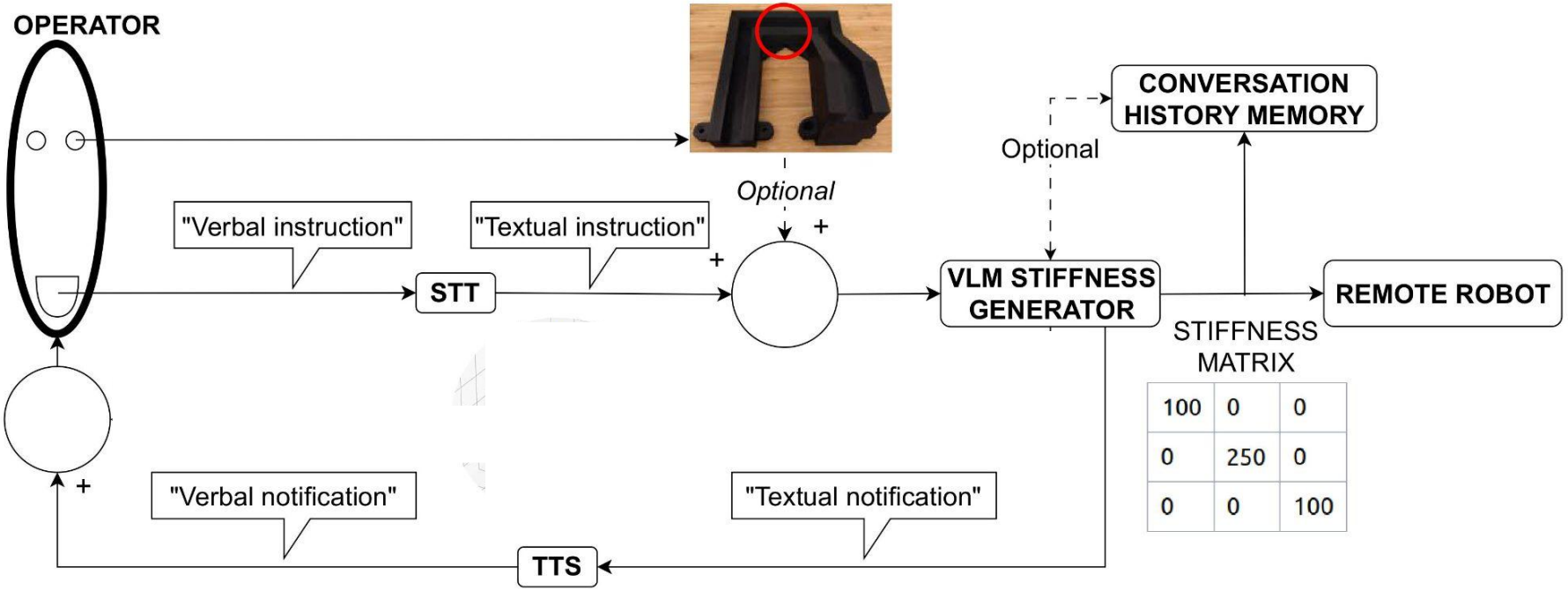

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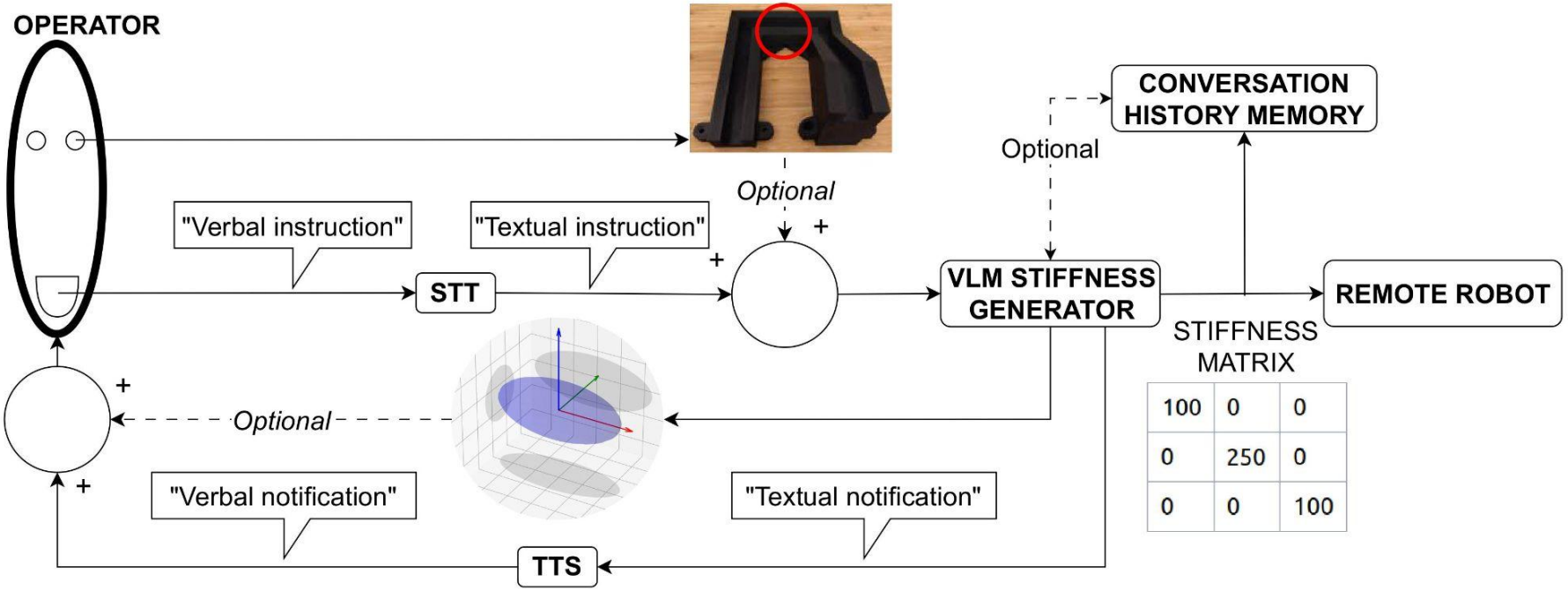
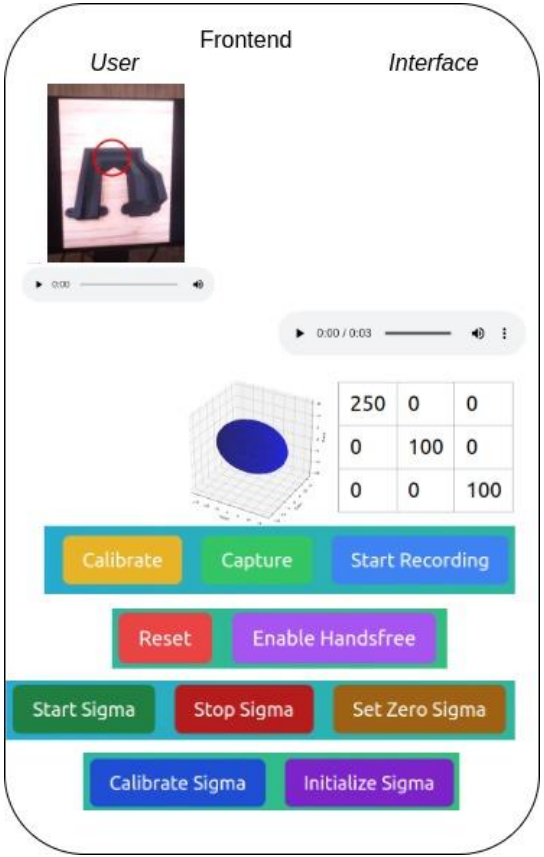
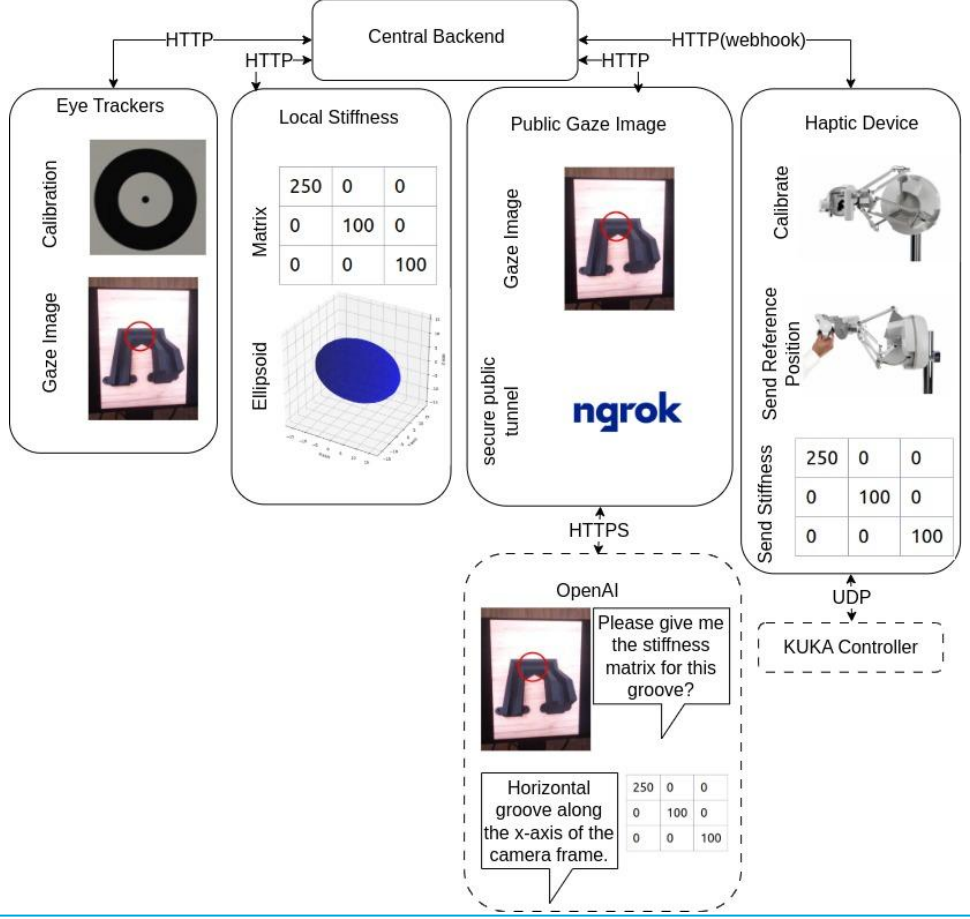


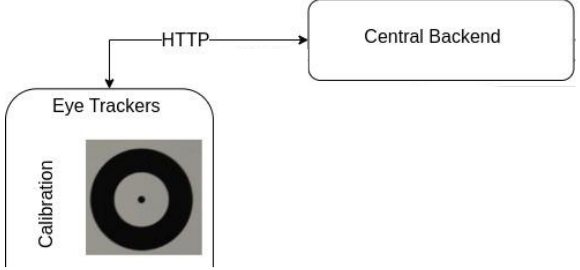
3. Software


Frontend
User
Interface
0:00 / 0:03
250 0 0
0 100 0
0 0 100
Calibrate
Capture
Start Recording
Reset
Enable Handsfree
Start Sigma
Stop Sigma
Set Zero Sigma
Calibrate Sigma
Initialize Sigma

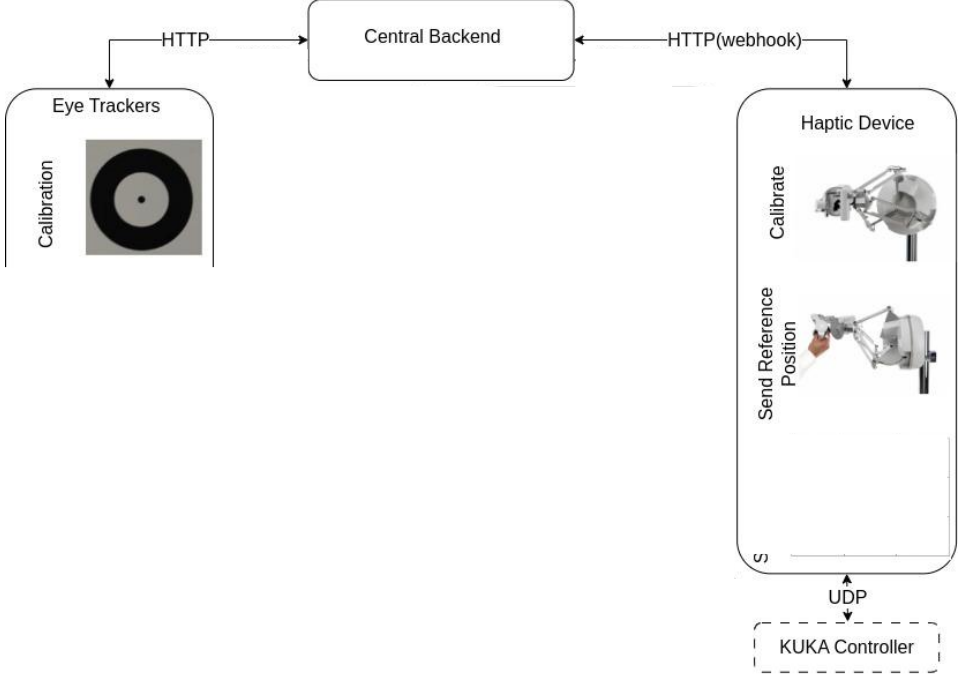
3. Software


Central Backend
HTTP
HTTP
HTTP
HTTP(webhook)
Eye Trackers
Calibration
Gaze Image
Local Stiffness
Matrix
250 0 0
0 100 0
0 0 100
Ellipsoid
Public Gaze Image
Gaze Image
secure public tunnel
ngrok
Haptic Device
Calibrate
Send Reference Position
Send Stiffness
250 0 0
0 100 0
0 0 100
HTTPS
UDP
KUKA Controller
OpenAI
Please give me the stiffness matrix for this groove?
Horizontal groove along the x-axis of the camera frame.
250 0 0
0 100 0
0 0 100

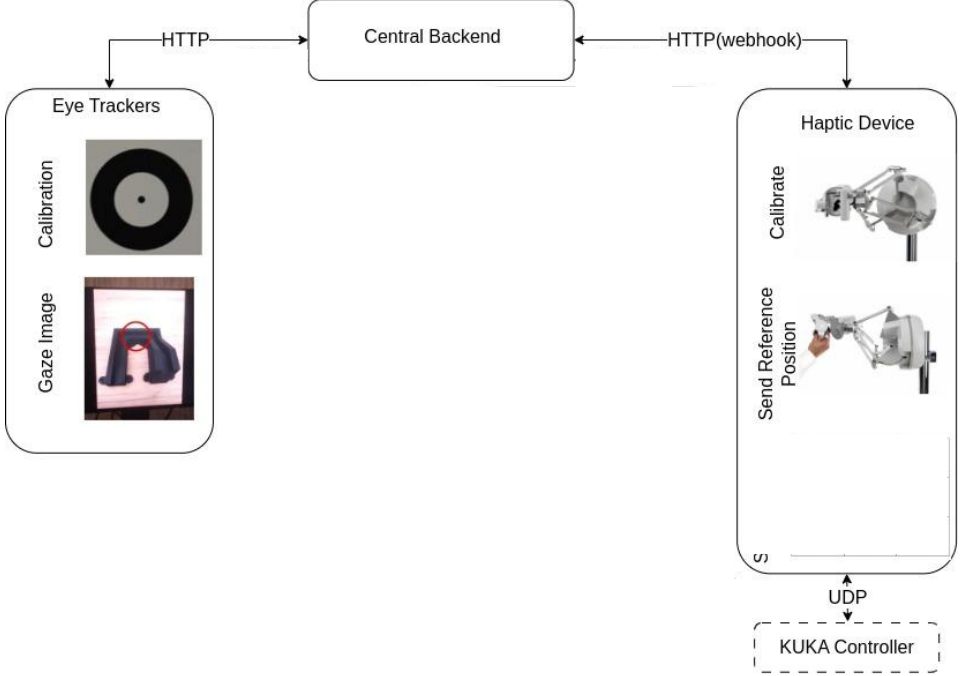
3. Software



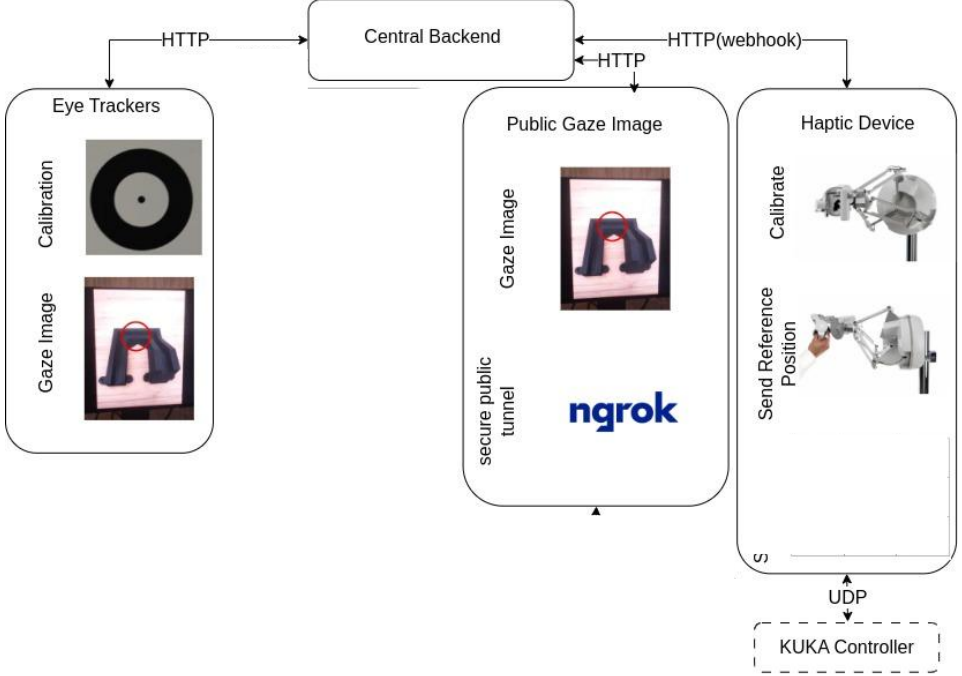
3. Software


HTTP
Central Backend
HTTP(webhook)
Eye Trackers
Calibration
Haptic Device
Calibrate
Send Reference Position
UDP
KUKA Controller

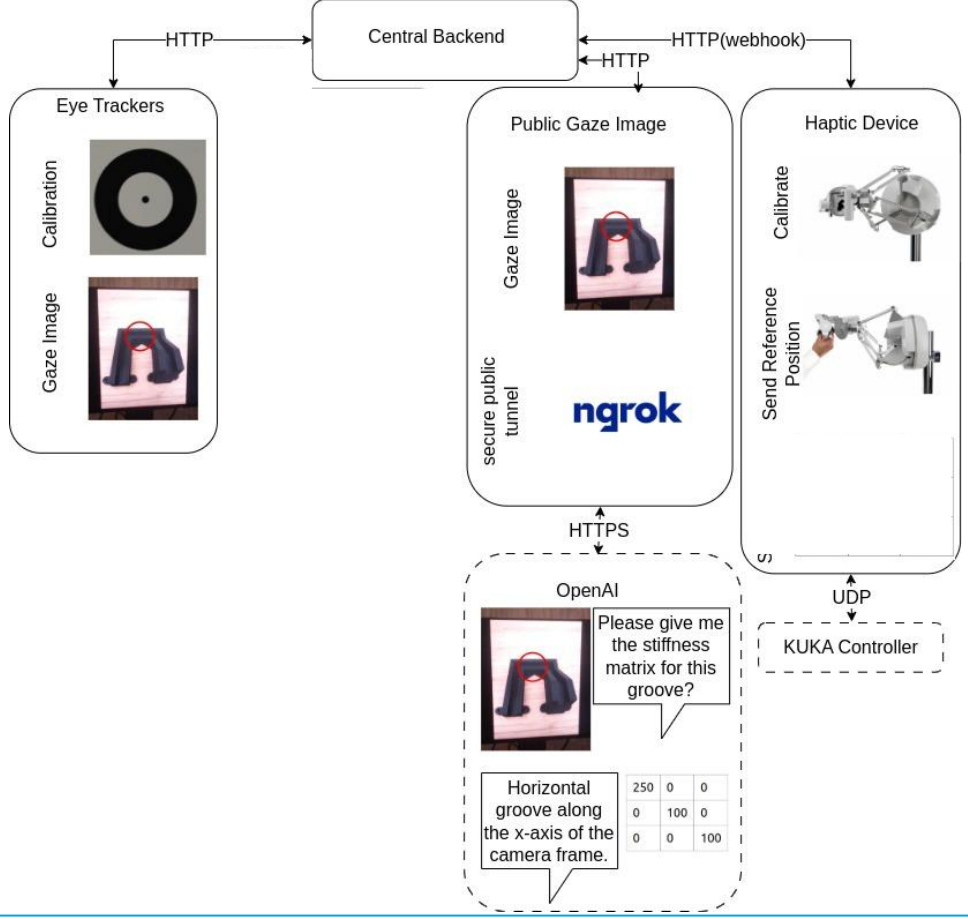
3. Software


HTTP
Central Backend
HTTP(webhook)
Eye Trackers
Calibration
Gaze Image
Haptic Device
Calibrate
Send Reference Position
UDP
KUKA Controller

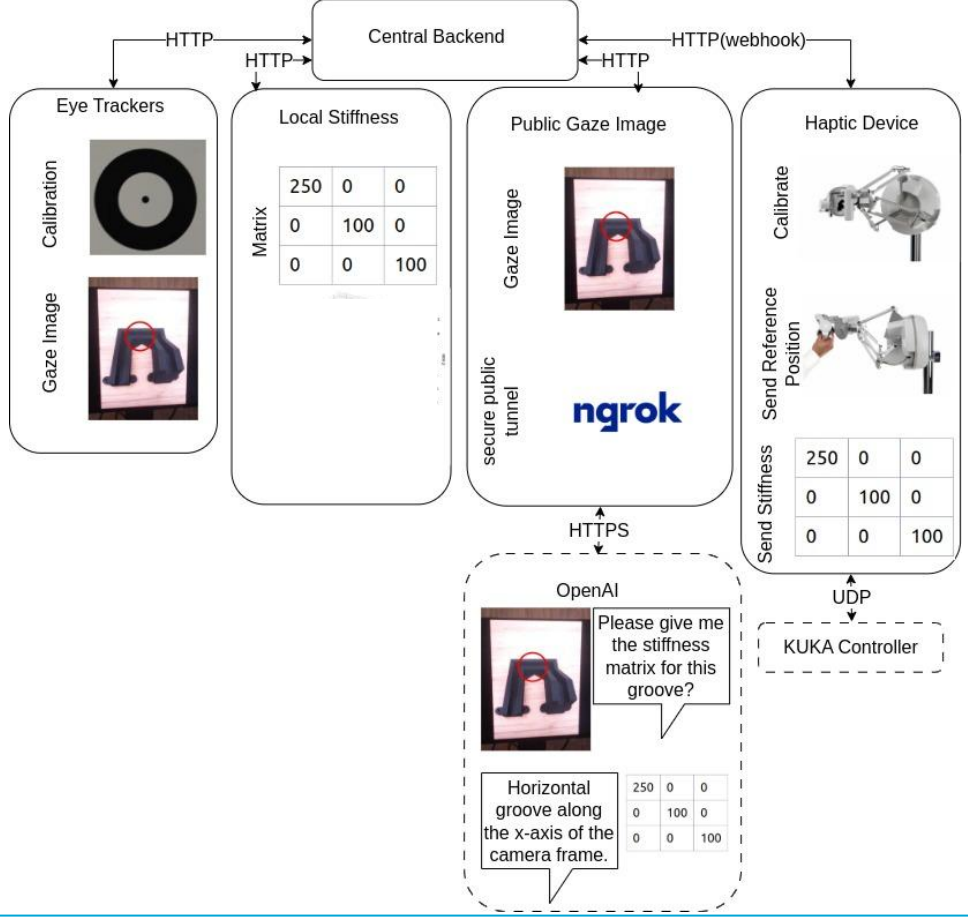
3. Software


Central Backend
HTTP
HTTP
HTTP(webhook)
Eye Trackers
Calibration
Gaze Image
Public Gaze Image
Gaze Image
secure public tunnel
ngrok
Haptic Device
Calibrate
Send Reference Position
UDP
KUKA Controller

3. Software


Central Backend
HTTP
HTTP
HTTP(webhook)
Eye Trackers
Calibration
Gaze Image
Public Gaze Image
Gaze Image
secure public tunnel
ngrok
Haptic Device
Calibrate
Send Reference Position
HTTPS
UDP
OpenAI
Please give me the stiffness matrix for this groove?
Horizontal groove along the x-axis of the camera frame.
250 0 0
0 100 0
0 0 100
KUKA Controller

3. Software


Central Backend
HTTP
HTTP
HTTP
HTTP(webhook)
Eye Trackers
Calibration
Gaze Image
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Matrix
250 0 0
0 100 0
0 0 100
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ngrok
Haptic Device
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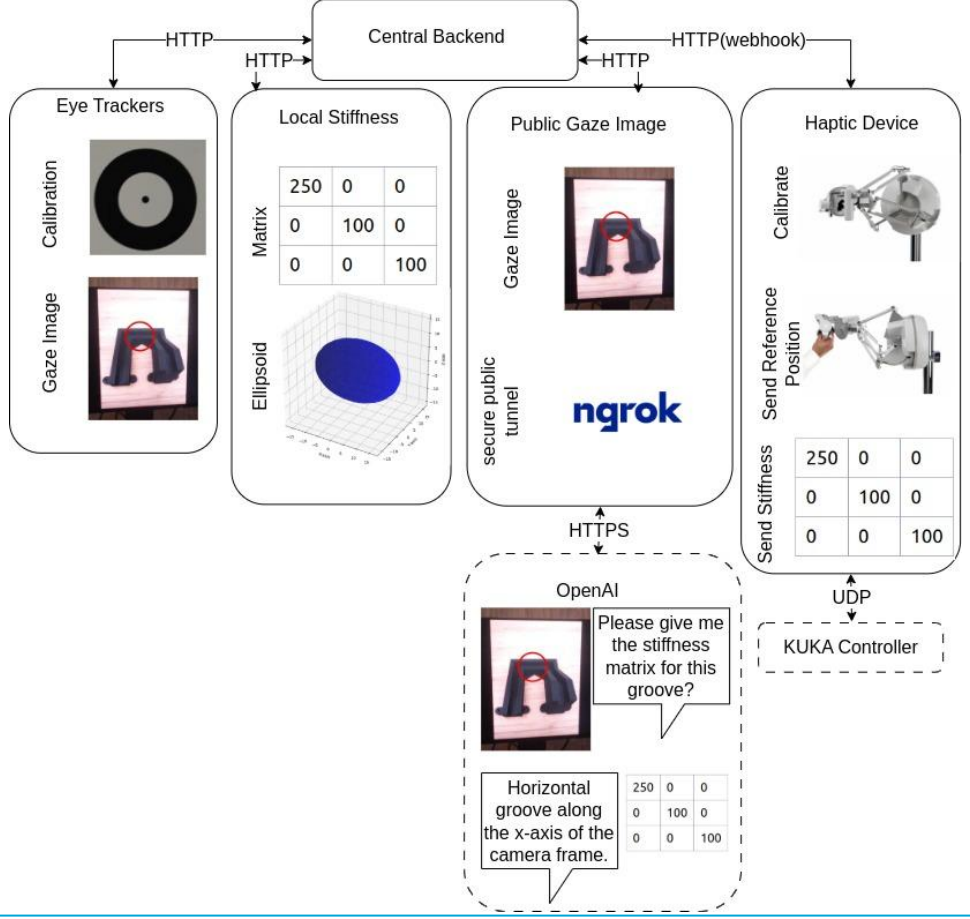
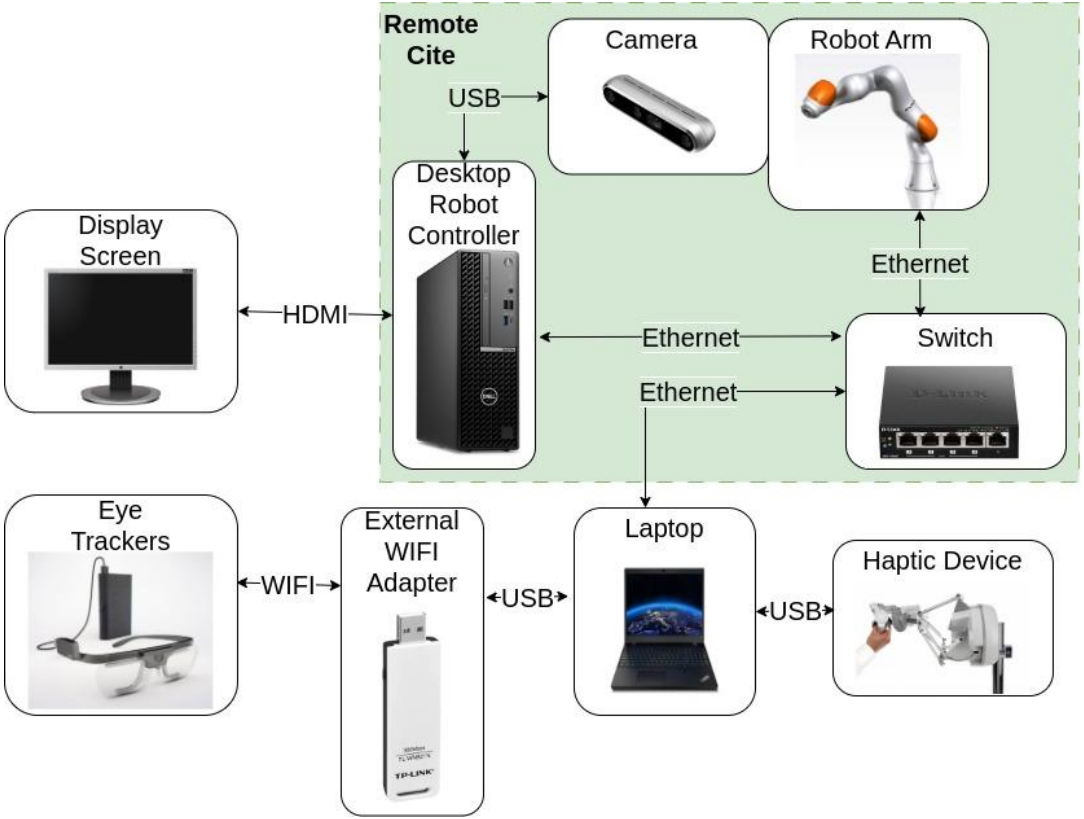
Send Stiffness
250 0 0
0 100 0
0 0 100
HTTPS
UDP
KUKA Controller
OpenAI
Please give me the stiffness matrix for this groove?
Horizontal groove along the x-axis of the camera frame.
250 0 0
0 100 0
0 0 100

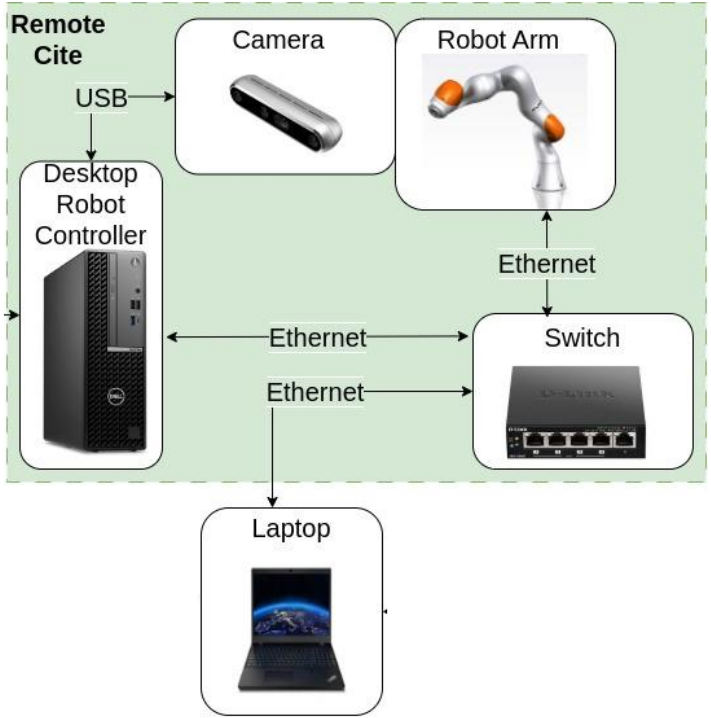
3. Software


Central Backend
HTTP
HTTP
HTTP
HTTP(webhook)
Eye Trackers
Calibration
Gaze Image
Local Stiffness
Matrix
250 0 0
0 100 0
0 0 100
Ellipsoid
Public Gaze Image
Gaze Image
secure public tunnel
ngrok
Haptic Device
Calibrate
Send Reference Position
Send Stiffness
250 0 0
0 100 0
0 0 100
HTTPS
UDP
KUKA Controller
OpenAI
Please give me the stiffness matrix for this groove?
Horizontal groove along the x-axis of the camera frame.
250 0 0
0 100 0
0 0 100

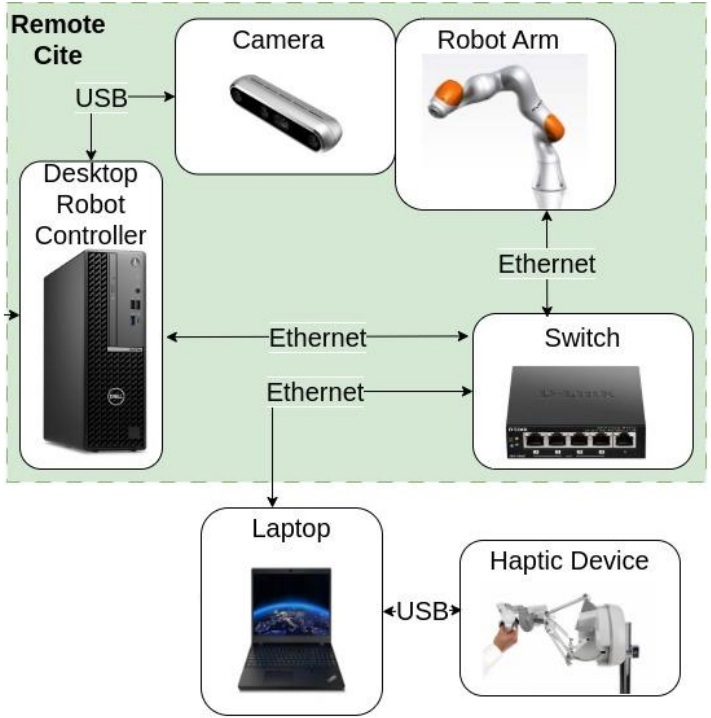
3. Hardware


Remote Cite
Camera
Robot Arm
USB
Desktop Robot Controller
Display Screen
HDMI
Ethernet
Ethernet
Switch
Ethernet
Eye Trackers
WIFI
External WIFI Adapter
USB
Laptop
USB
Haptic Device

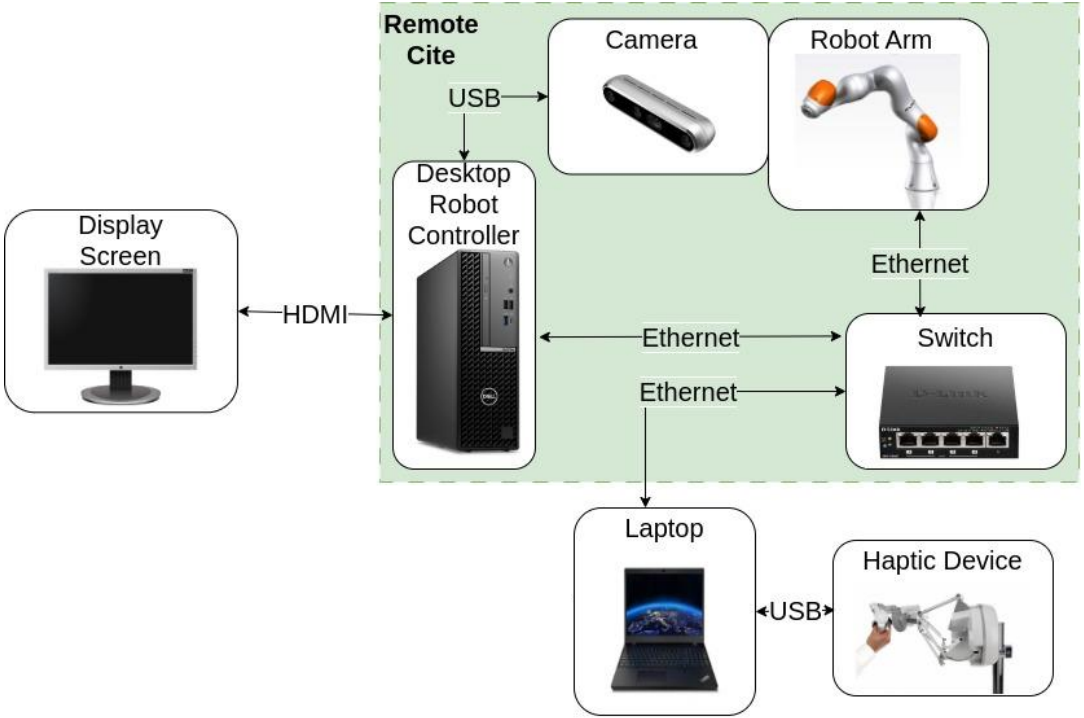
3. Hardware


Remote Cite
Camera
Robot Arm
USB
Desktop Robot Controller
Ethernet
Ethernet
Switch
Ethernet
Laptop

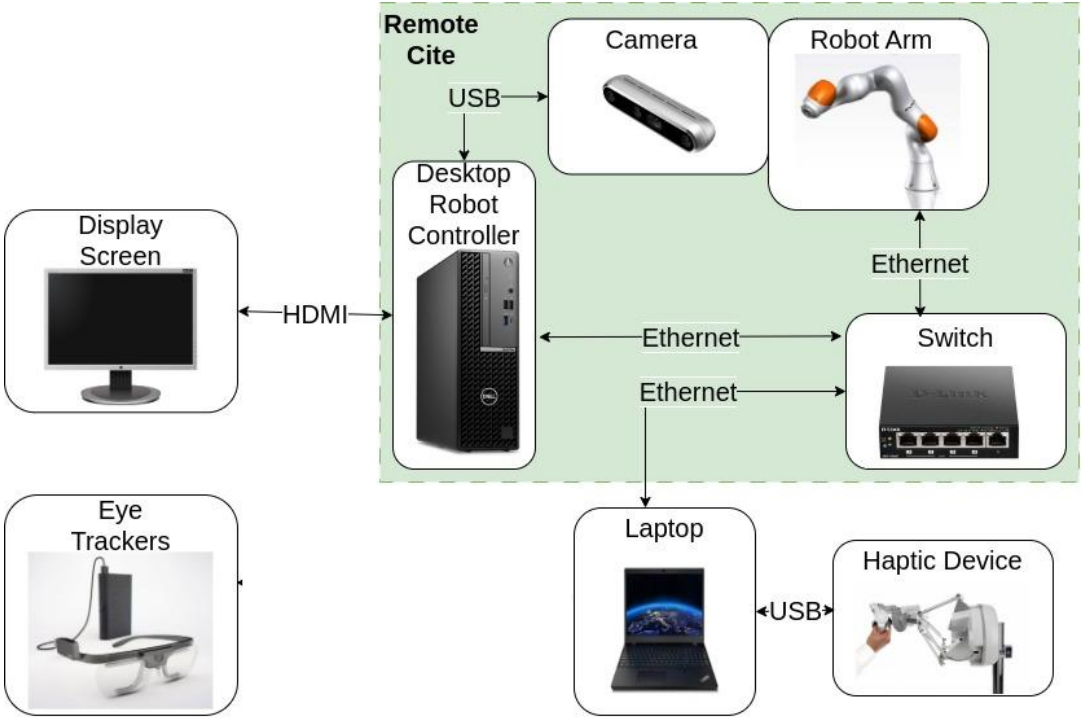
3. Hardware


Remote Cite
Camera
Robot Arm
USB
Desktop Robot Controller
Ethernet
Ethernet
Switch
Ethernet
Laptop
Haptic Device
USB

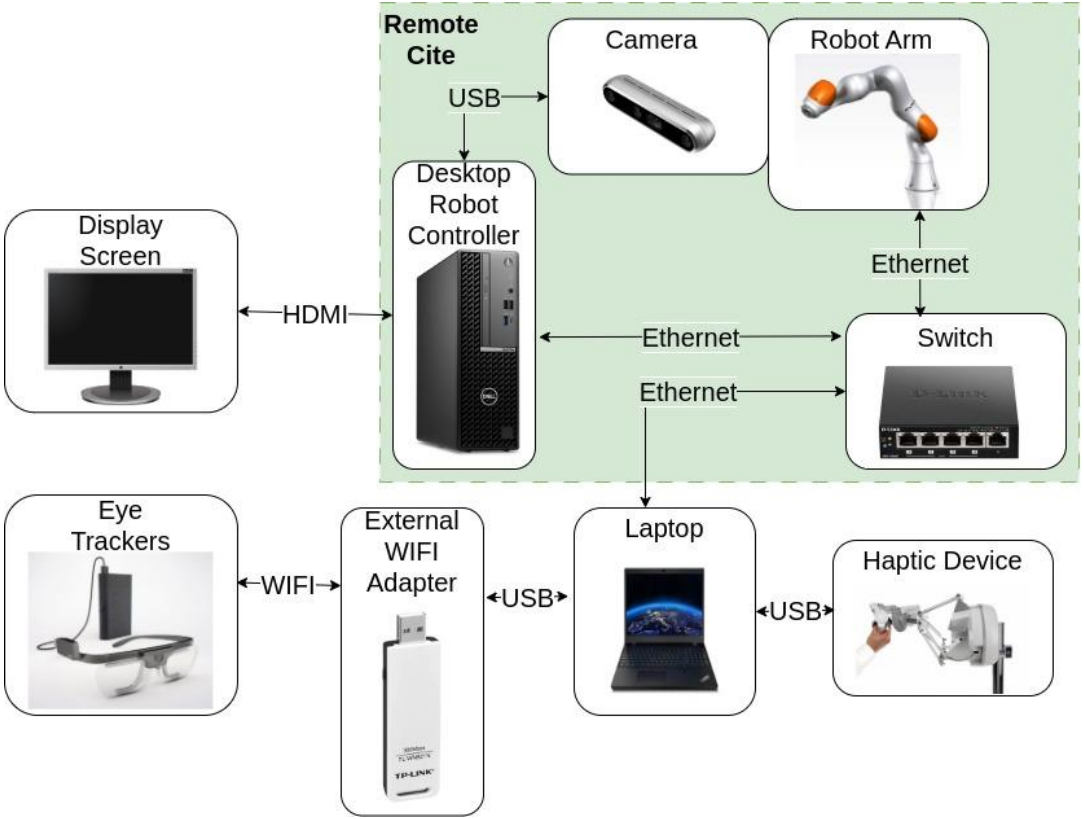
3. Hardware


Remote Cite
Camera
Robot Arm
USB
Desktop Robot Controller
Display Screen
HDMI
Ethernet
Ethernet
Switch
Ethernet
Laptop
Haptic Device
USB

3. Hardware


Remote Cite
Camera
Robot Arm
USB
Desktop Robot Controller
Display Screen
HDMI
Ethernet
Ethernet
Switch
Ethernet
Eye Trackers
Laptop
Haptic Device
USB

3. Hardware


Remote Cite
Camera
Robot Arm
USB
Desktop Robot Controller
Display Screen
HDMI
Ethernet
Ethernet
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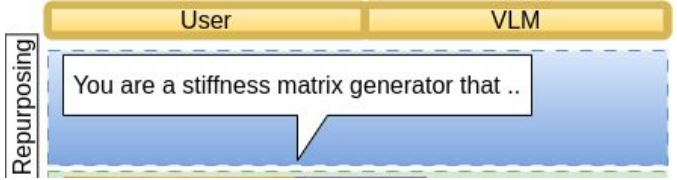
Ethernet
Eye Trackers
WIFI
External WIFI Adapter
USB
Laptop
USB
Haptic Device

3. Software

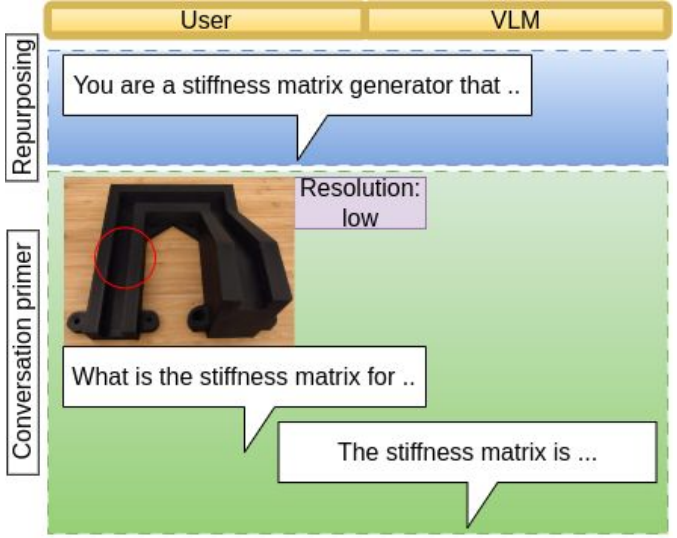

OpenAI
Please give me the stiffness matrix for this groove?
Horizontal groove along the x-axis of the camera frame.
250 0 0
0 100 0
0 0 100

4. Prompt

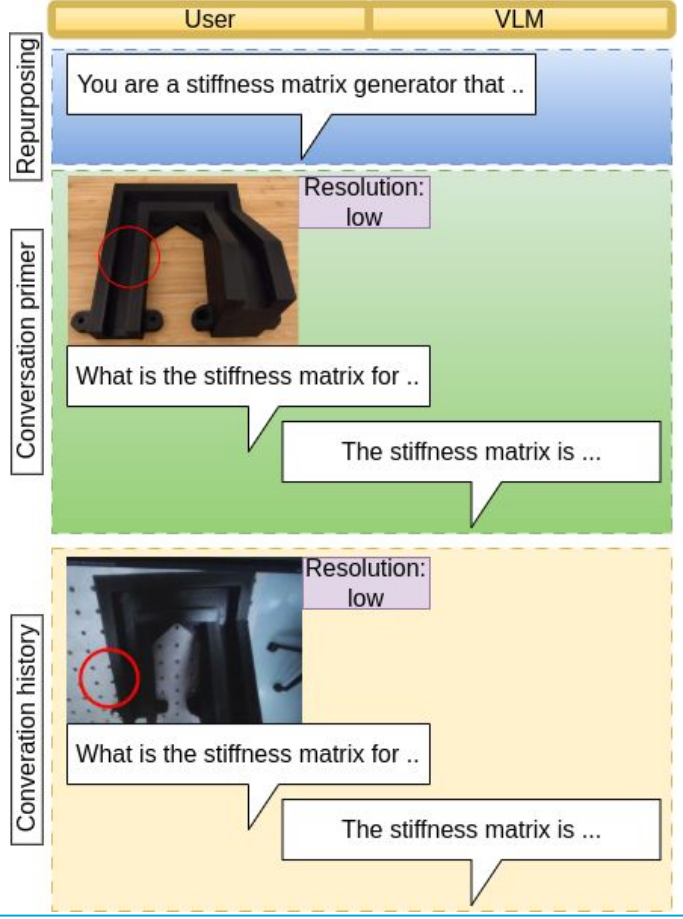
4. Prompt


User
VLM
Repurposing
You are a stiffness matrix generator that ..

4. Prompt


User
VLM
Repurposing
You are a stiffness matrix generator that ..
Conversation primer
Resolution: low
What is the stiffness matrix for ..
The stiffness matrix is ...

4. Prompt


User
VLM
Repurposing
You are a stiffness matrix generator that ..
Conversation primer
Resolution: low
What is the stiffness matrix for ..
The stiffness matrix is ...
Conversation history
Resolution: low
What is the stiffness matrix for ..
The stiffness matrix is ...

4. Experiments

4. Experiments: Prompt configuration

Task Description

4. Experiments: Prompt configuration

Task Description
Minimal task description
Elaborate task description
Elaborate task description + labels (examples)

4. Experiments: Prompt configuration

Task Description	Conversation Primer
Minimal task description Elaborate task description Elaborate task description + labels (examples)	

4. Experiments: Prompt configuration

Task Description	Conversation Primer
Minimal task description	None
Elaborate task description	Home examples
Elaborate task description + labels (examples)	Lab examples

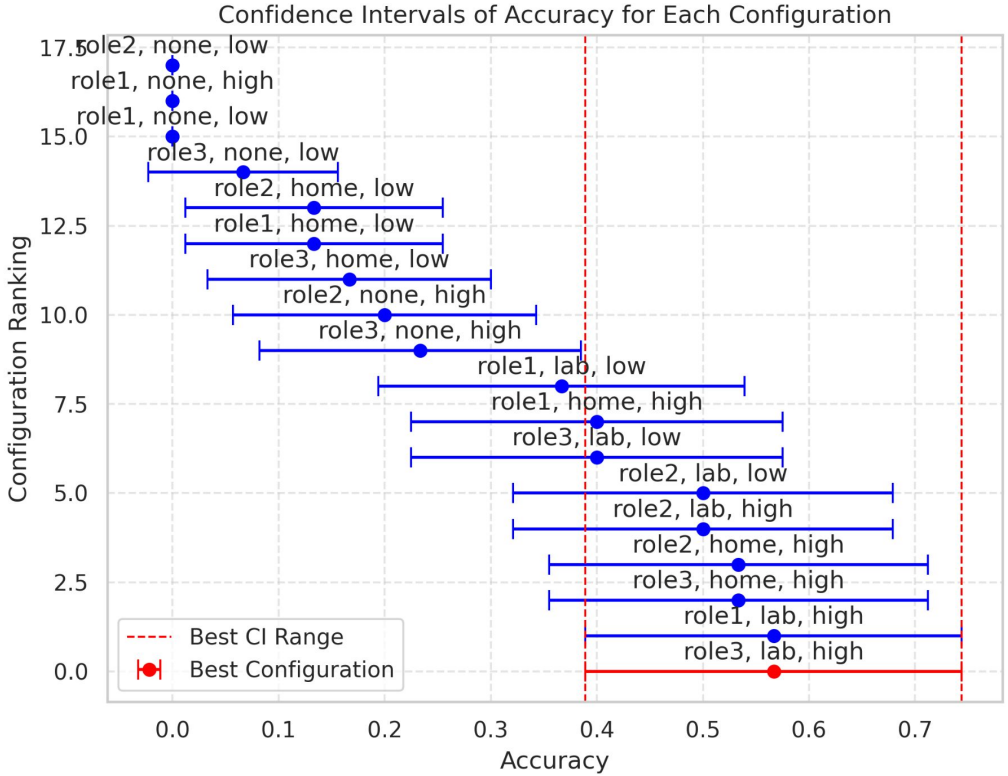
4. Experiments: Prompt configuration

Task Description	Conversation Primer	Image Processing Mode
Minimal task description	None	
Elaborate task description	Home examples	
Elaborate task description + labels (examples)	Lab examples	

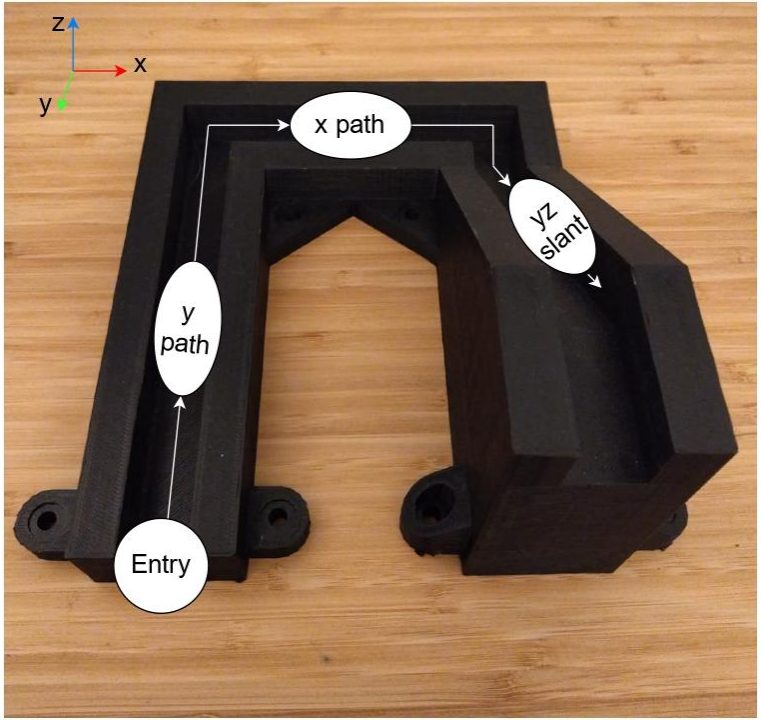
4. Experiments: Prompt configuration

Task Description	Conversation Primer	Image Processing Mode
Minimal task description	None	Low detail
Elaborate task description	Home examples	High detail
Elaborate task description + labels (examples)	Lab examples	

4. Experiments: Prompt configuration

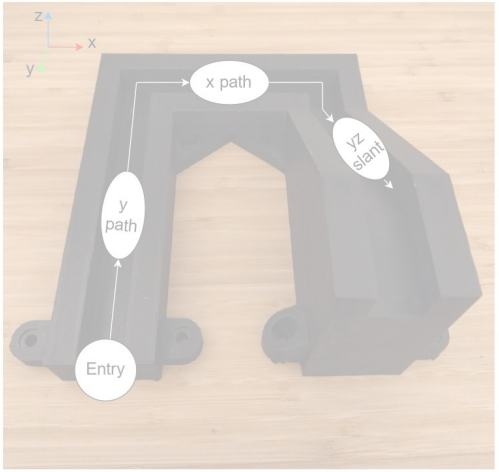


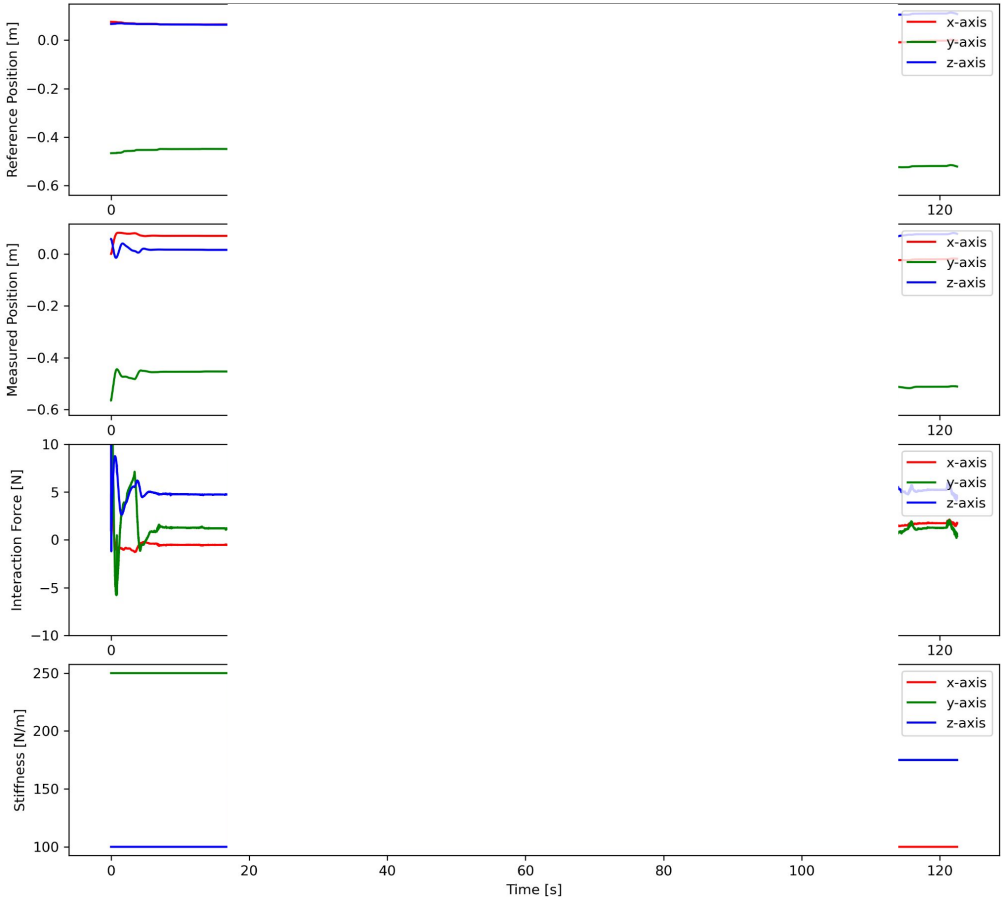
3. Visio-Verbal Interface: Experiments



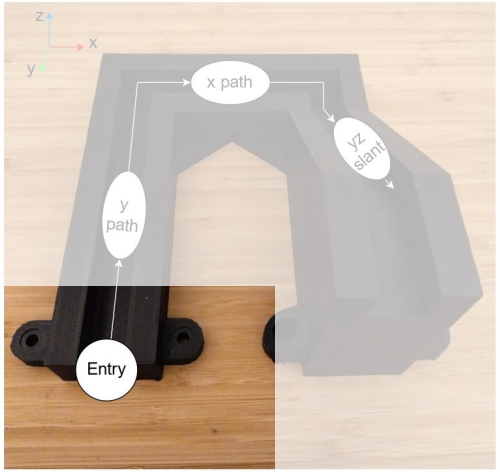
4. Experiments: voice-only interface

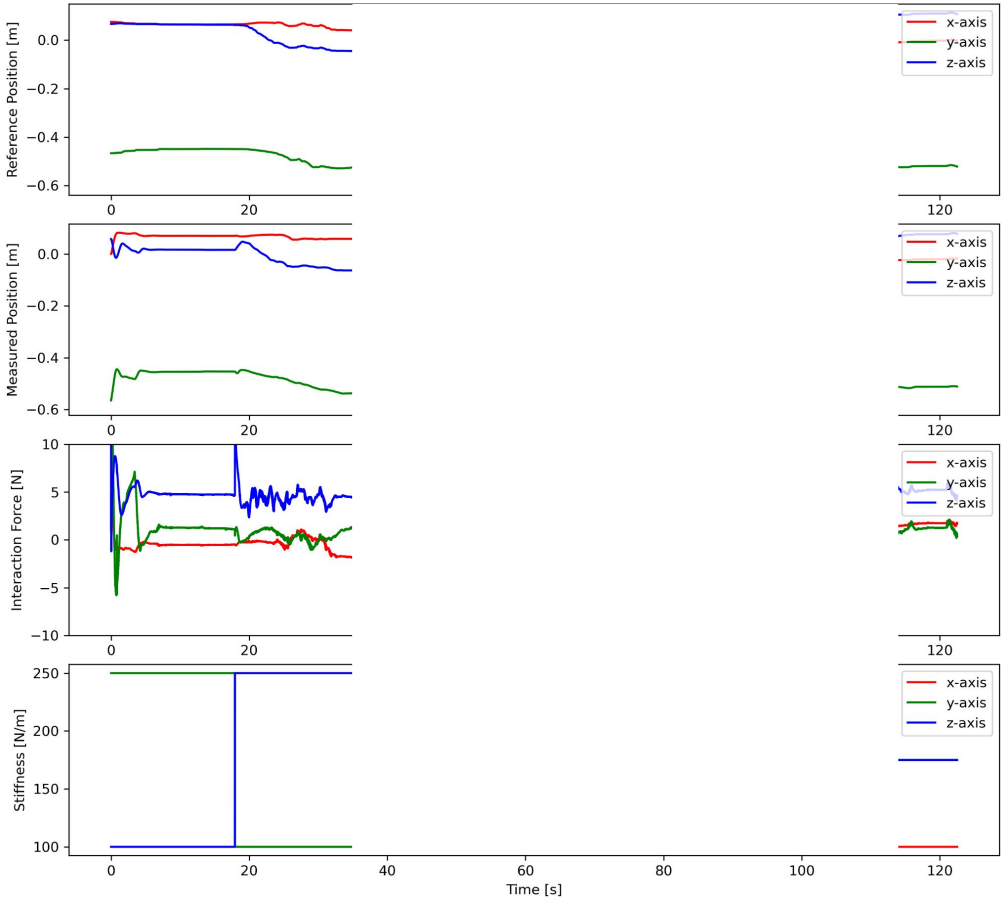
4. Experiments



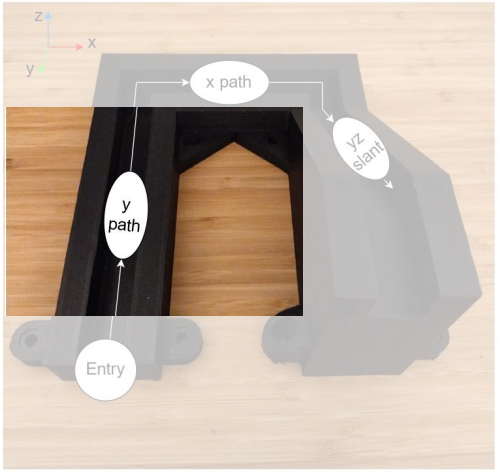


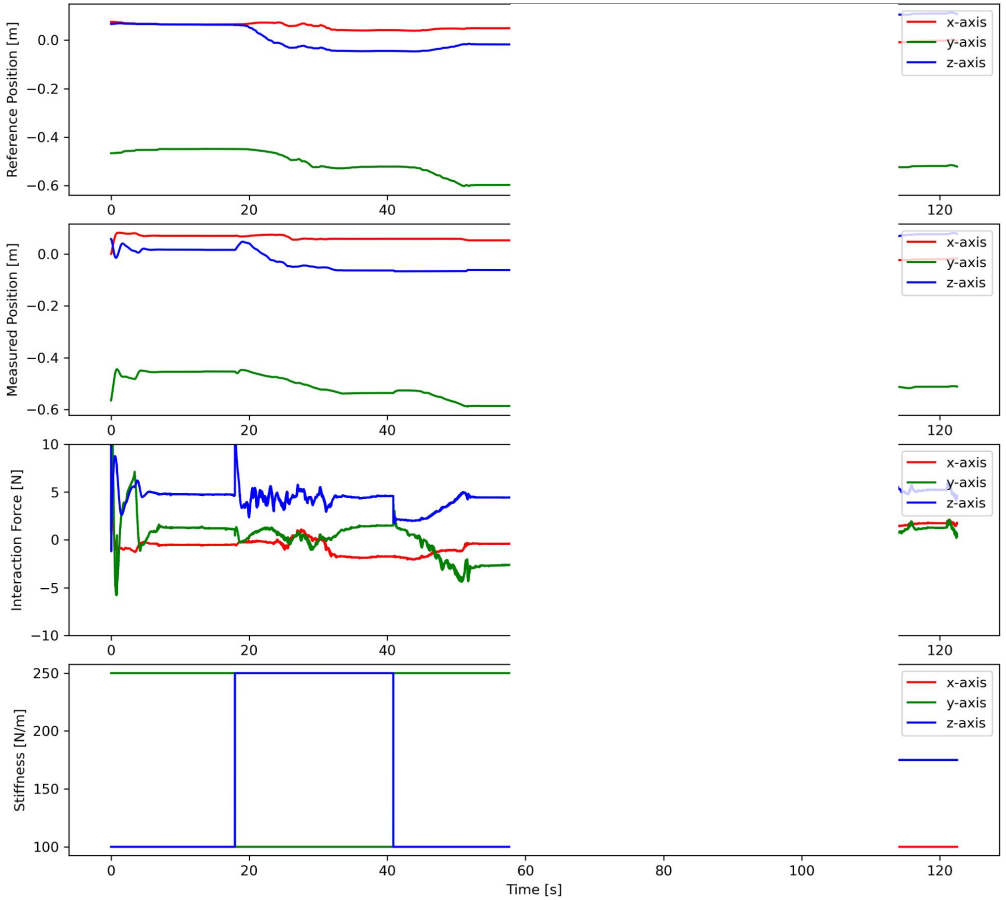
4. Experiments



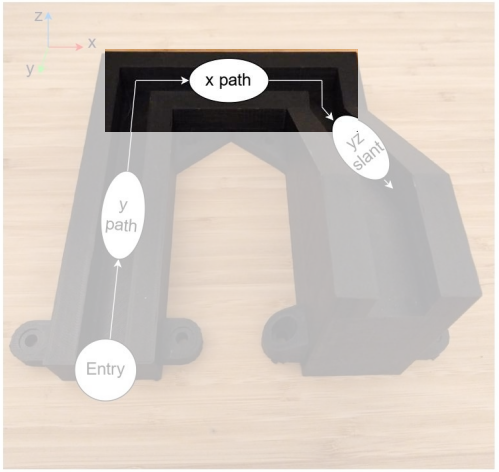


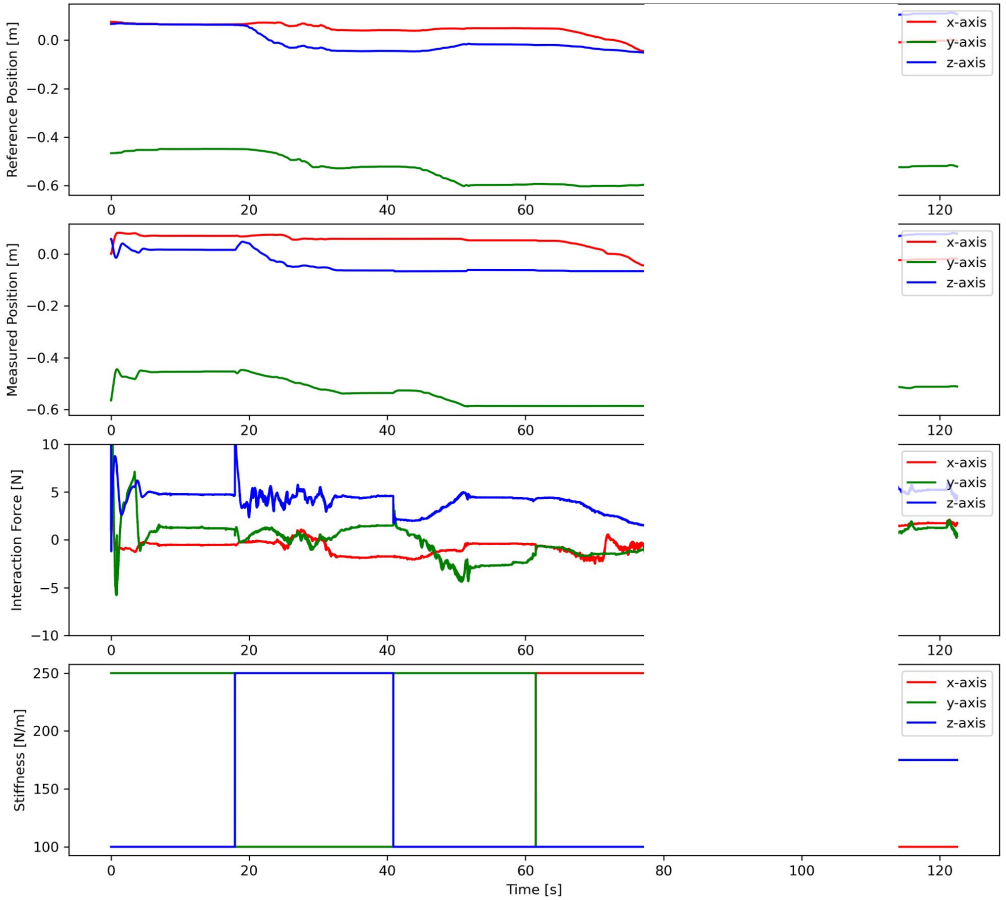
4. Experiments



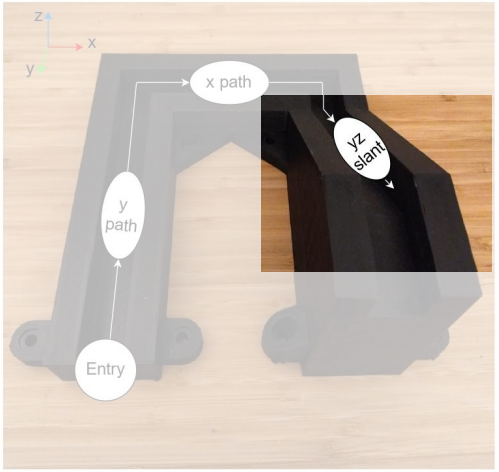


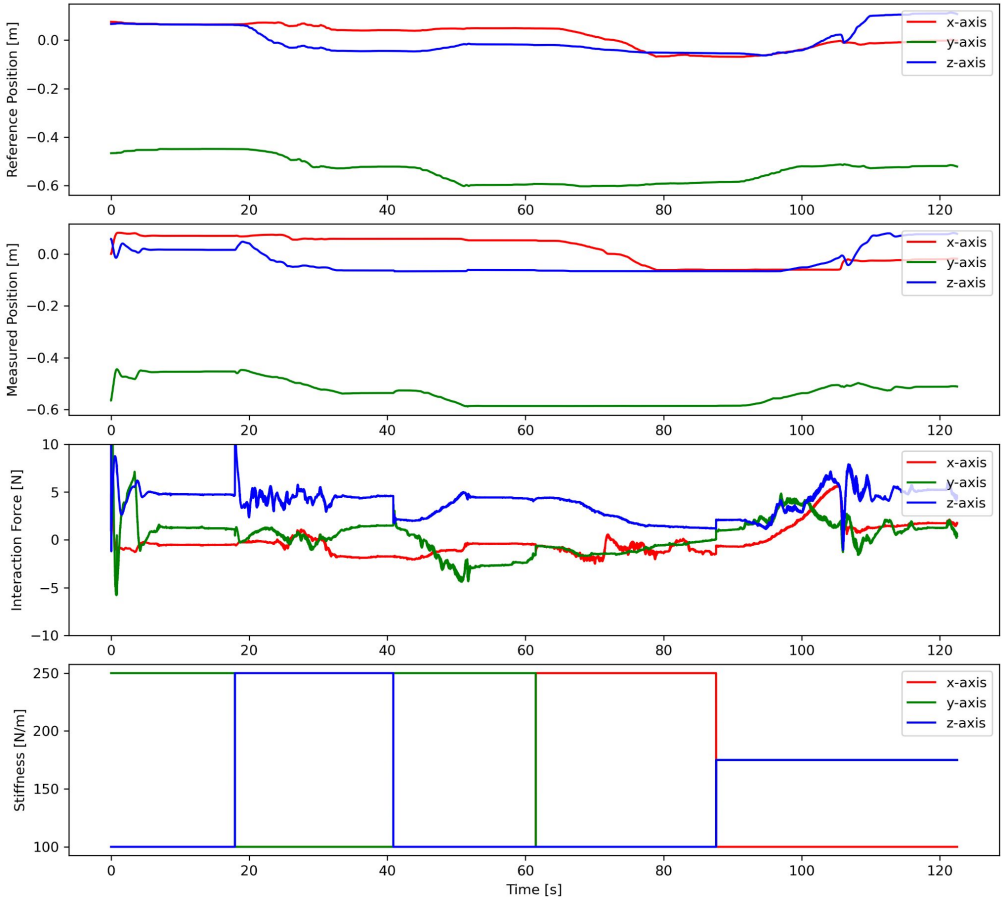
4. Experiments





4. Experiments





References

- 1 Peternel L, Tsagarakis N, Ajoudani A (2017), A human–robot co-manipulation approach based on human sensorimotor information. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 25(7):811-22.
- 2 Peternel, L., Petrič, T., & Babič, J. (2018). Robotic assembly solution by human-in-the-loop teaching method based on real-time stiffness modulation. *Autonomous Robots*, *42*(1), 1-17.
- 3 Peternel, L., & Ajoudani, A. (2022). After a decade of teleimpedance: A survey. IEEE Transactions on Human-Machine Systems, PP(99), 1–16.
- 4 Peternel, L., & Ajoudani, A. (2020). Independently commanding size, shape and orientation of robot endpoint stiffness in tele-impedance by virtual ellipsoid interface. *IEEE Transactions on Haptics*, 13(4), 699–704.
- 5 Michel, Y., Rahal, R., Pacchierotti, C., Robuffo Giordano, P., & Lee, D. (2022). Bilateral teleoperation with adaptive impedance control for contact tasks. *IEEE Transactions on Robotics*, 38(6), 3647–3666.
- 6 Huang, Y.-C., Abbink, D. A., & Peternel, L. (2021). A semi-autonomous tele-impedance method based on vision and voice interfaces. IEEE Transactions on Haptics, 14(4), 845–856.

Thank you for your attention.

Drawbacks of Current Methods in Literature: Automated Approaches

✅ **Advantages**: Reduces operator workload, adapts stiffness autonomously.
❌ **Challenges**:

- **Loss of Human Oversight**: Fully automated systems make it hard for the operator to intervene.
- **Limited Adaptability**: Pre-set stiffness adjustments may not account for unstructured environments.

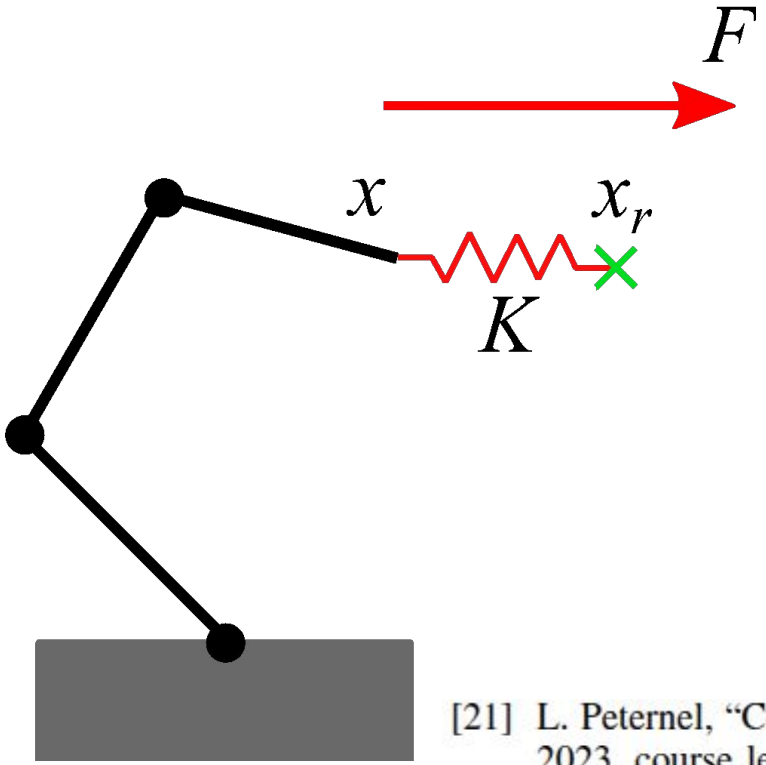
Feedback

Good: Visuals, technical explanations

Bad: Why? Explain the reason why we did this. Visuals why it is important. Introduction is not there. Remove outline, explain why teleimpedance is important. Video of existing interfaces. At least pictures. Why teleoperation? Convince that it is important. Space, robotics, robotic arm space station, maintenance remote, fukushima, surgery. One slide. Space remoteness, inspection remoteness, hazardous remoteness. disaster, collapse. surgery sometimes precision.

No sandwich, top bread introduction bottom discussion.

1. Understand Teleimpedance



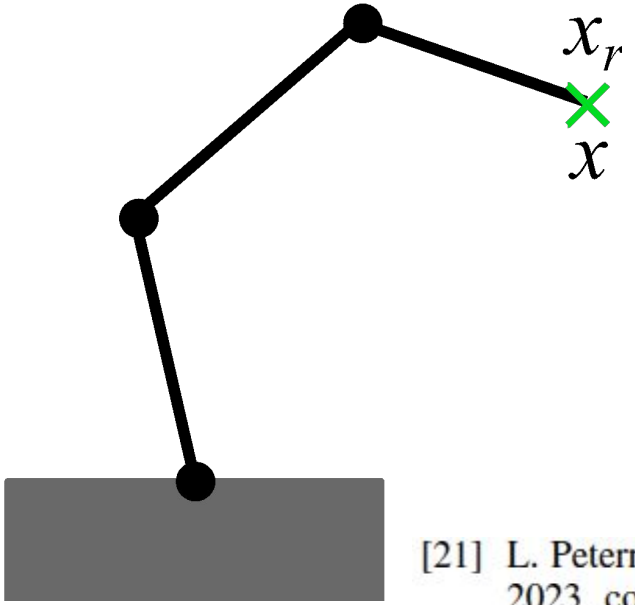
Note: virtual spring of the controller produces a force that acts toward the reference position, which is the equilibrium of the spring.

$$F = K(x_r - x) - D\dot{x}$$

$$x_r \neq x \rightarrow F = K\,x$$

[21] L. Peternel, "Control in human-robot interaction," Lecture slides, 2022–2023, course lecture slides.

1. Understand Teleimpedance

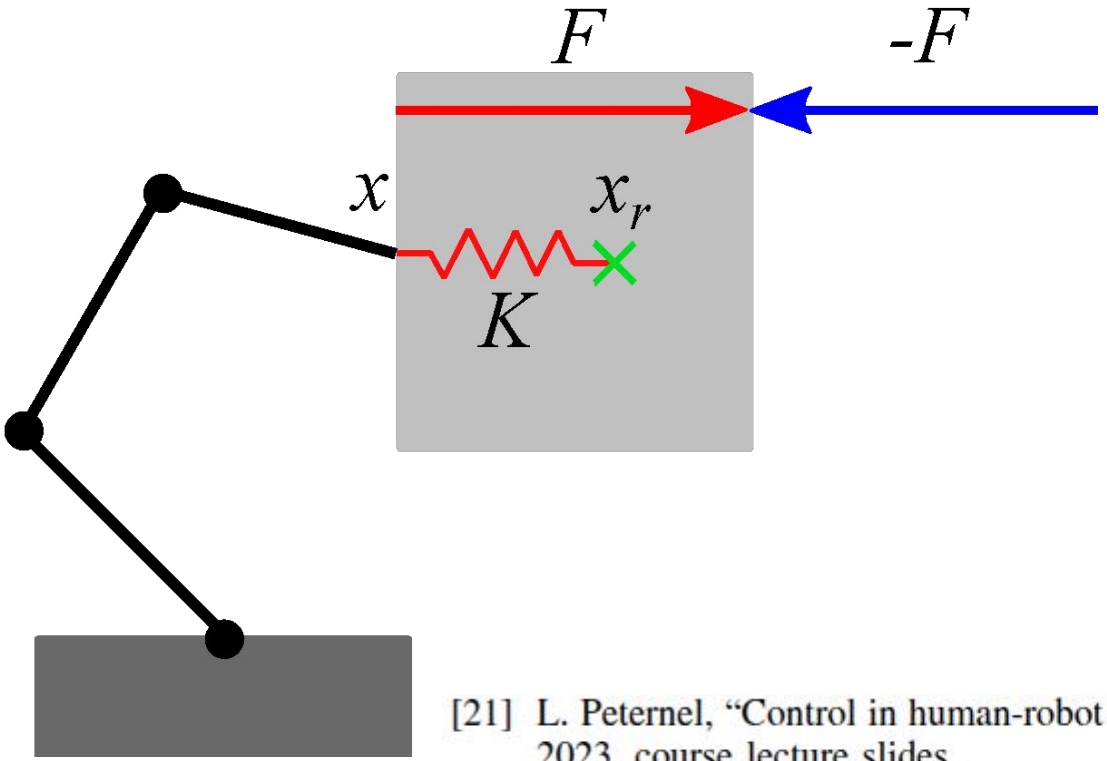


$$F = K(x_r - x) - D\dot{x}$$

$$x_r = x \rightarrow F = 0$$

[21] L. Peternel, "Control in human-robot interaction," Lecture slides, 2022–2023, course lecture slides.

1. Understand Teleimpedance



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