Teleoperation over 5G networks

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Although conversational services are bidirectional, audiovisual data communication is 2x unidirectional.
**Telepresence + Haptics = Teleoperation**


Teleoperation over 5G Networks

- Remote environment can be real or virtual
Haptics

Kinesthetic Perception

Tactile Perception

Image Source: Katsunari Sato, Dept. of MEIP, The University of Tokyo/Japan

position & forces

sense of touch of the skin

Perception of form, position, surface texture, stiffness, friction, temperature, etc.
Teleoperation with kinesthetic feedback

Position / Velocity

Operator

Force / Torque Feedback

Teleoperator

Network

Closed loop communication

1000 – 4000 Hz sampling/packet rate

Very strict delay constraints (< 10ms)

Lack of realism (hard contacts / surface details)
Demo: Strict delay constraint

Operator  Force Feedback  Teleoperator

Delay: 0 ms
Teleoperation with tactile feedback

Open loop communication

Relaxed delay constraints

Improved realism
Communication of kinesthetic/tactile data

- Communication of **kinesthetic** information
- Communication of **tactile** information
Communication of kinesthetic data: Packet rate reduction

Perceptual haptic data reduction [1]
- exploits limits of human haptic perception
- packet rate reduction of up to 90% (no perceivable distortion)
- leads to a variable packet rate → event-based sampling and communication

Communication of **kinesthetic data**: Time-delayed teleoperation

- Delay
- Damping (control)
- Transparency
Time-delayed Teleoperation: Passivity-based

B. Hannaford, and J. Ryu, 2002

Stable haptic interaction for delays 10ms ... 100ms

Energy dissipation leads to reduced transparency
**Time-delayed Teleoperation: Model-mediated**

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**Stable haptic interaction for delays 10ms ... 200ms**

**Model errors / updates lead to reduced transparency**

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B. Hannaford, 1989  
P. Mitra and G. Niemeyer, 2008  
Demo: TDPA + Perceptual coding für different RTT

delay: 0 ms
Control & communication for different delay ranges

- Wave variable approach
- Time-domain passivity control
- Model-mediated teleoperation

end-to-end delay

best possible performance
Joint optimization of communication and control

Experience (QoE) → joint optimization → Task Performance (QoTP) → Network (QoS) → Control (QoC)

Joint optimization including the knowledge about the human user

Experience, Task Performance, Control, and Network QoE, QoTP, QoC, QoS are connected through models and metrics.
Example: Physical coupling of two users in a VE

Joint work with W. Kellerer and his team (LKN@TUM)
Communication of kinesthetic/tactile data

- Communication of *kinesthetic* information
- Communication of *tactile* information
Surface Material Perception

Friction
(Moist/Dry, Sticky/Slippery)

Hardness
(Hard/Soft)

Warmness
(Warm/Cold)

Fine roughness
(Rough/Smooth)

Macro roughness
(Uneven, Relief)

Roughness

Source: Okamoto et al., 2013
Surface Analysis Devices

- Force Sensing Resistors (FSR)
- Acceleration Sensor
- Stainless Steel Tooltip
- DAQ NI SCB-68
- Magnifying Lens
- Microphone CMP-MIC8

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Surface Analysis Devices

Texplorer Device

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Tactile feedback displays: Tactile Mouse
Combination of kinesthetic and tactile teleop + ultra low delay 360° stereoscopic video
Summary

- Fundamental difference between **kinesthetic** interaction (closed-loop) and **tactile** feedback (open-loop)
- Different **control approaches** for different delay ranges and remote environments → joint optimization of 5G network and teleoperation application
- **Combination of kinesthetic and tactile information** significantly increases realism of teleoperation