Haptic Communication for the Tactile Internet

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Telepresence

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

Operator performance increases significantly in telemanipulation of remote objects when haptic feedback is provided


In this talk: **Human-in-the-loop TI**
- Focus is on **Quality of Interaction**
- Remote environment can be real or virtual
Haptics

Kinesthetic Perception

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

position & forces

Tactile Perception

sense of touch of the skin

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

Closed loop communication

- **Position / Velocity**
- **Force / Torque Feedback**

Network

**Operator**

**Teleoperator**

- **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

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

Energy dissipation leads to reduced transparency

B. Hannaford, and J. Ryu, 2002
Time-delayed Teleoperation: Model-mediated

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

Model errors / updates lead to reduced transparency

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

- Best possible performance
- Wave variable approach
- Time-domain passivity control
- Model-mediated teleoperation
- End-to-end delay
Joint optimization of communication and control

Joint optimization including the knowledge about the human user
Shared Haptic Virtual Environments (SHVEs)
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
Vibrotactile communication
Communication of tactile information

Vibrotactile signals are similar to speech signals

R. Chaudhari et al., IEEE JSTSP 2015

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Sine detection thresholds and masking

Thresholds [dB re 1 m/s²]

Frequency [Hz]

-22
-28
-34
-40
-46
-52
-58
-64
-70

Masking thresholds
BPF responses
Detection thresholds (literature)
Detection thresholds

R. Chaudhari et al., IEEE JSTSP 2015

custom-made stylus-like handle mounted on Mini SmartShaker™
Surface Material Perception

- Hardness (Hard/Soft)
  - Friction (Moist/Dry, Sticky/Slippery)
  - Warmness (Warm/Cold)
- Roughness
  - Fine roughness (Rough/Smooth)
  - Macro roughness (Uneven, Relief)

Source: Okamoto et al., 2013
Surface Analysis Devices

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

Texplorer Device

- Reflectance Signal
- SMA

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Tactile feedback displays: Electrovibration-based
Tactile feedback displays: Tactile Mouse
What about video?

Light Source (LED)  | Camera  | Processing, Transmission | Display  | Light Sink (PT)

Measuring G2G delay

Build instructions, Android Application and Arduino source code are available under http://tinyurl.com/G2GDelay

Source: www.android.com

Source: www.arduino.cc
G2G Delay Survey: Results

- Video conferencing systems
- G2G delay > 200ms
G2G Delay Survey: Results

- Video feedback in drone remote control
- DJI > 250ms (focus on high quality and reliability)
- FatShark analog 28ms
- FatShark digital 55ms

Source: www.droneuplift.com
G2G Delay Survey: Results

- Smartphones camera app 80-100ms

Source: www.pcadvisor.co.uk
G2G Delay Survey: Results

- Ultra-low delay solution
  LMT@TUM
- 15ms (uncompressed video)
- 19ms (compressed video)
Demo video

Ultra-Low Delay Video Transmission
and Video Delay Measurement

Chair of Media Technology, Technical University of Munich
Standardization

https://standards.ieee.org/develop/project/1918.1.html
Task Group: Haptic Codecs for the Tactile Internet

http://grouper.ieee.org/groups/1918/1/haptic_codecs/index.html

- IEEE P1981.1.1

- **Chair**: Eckehard Steinbach (TUM), **Vice Chair**: Mohammad Eid (NYUAD), **Secretary**: Qian Liu (Dalian Univ.)

- **Scope**
  - Protocol for the *exchange of device capabilities* (handshaking)
  - (Perceptual) codec for closed-loop *kinesthetic* information
  - (Perceptual) codec for open-loop *tactile* information
Summary

- **Haptic communication** as a key technology for physical interaction across networks
- Fundamental difference between *kinesthetic* interaction (closed-loop) and *tactile* feedback (open-loop)
- Compression of kinesthetic data **fundamentally different** from A/V
- *Time-delayed teleoperation* requires joint optimization of communication, compression and control
- Different *control approaches* for different delay ranges
- *Tactile feedback displays* open new opportunities
- G2G delay of *video communication solutions* needs to be further reduced
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The end

Thank you!