Haptic feedback in teleoperated hand-arm robot actions

Bachelor Thesis

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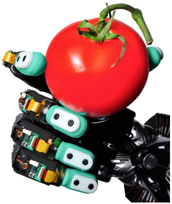
Motivation

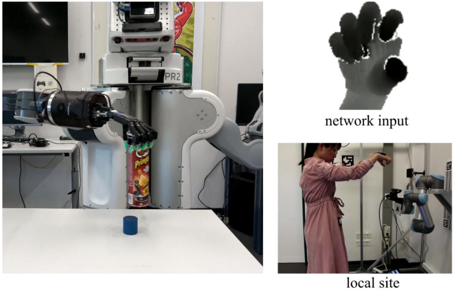
- Development of a prototype glove for haptic feedback to users from a Shadow Dexterous Hand with Biotac-Sensors

 [1]

[1] *SynTouch Biotac*. URL: https://syntouchinc.com/

Challenges in a Hand-Arm Teleoperation

- remotely located robot
- 2D visual feedback
- occlusions
- cognitive demand

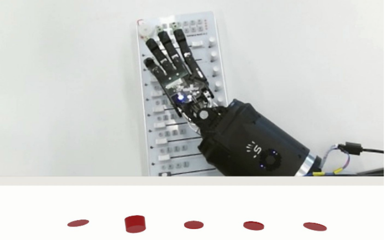


[2]

[2] Shuang Li. "Vision-based Perception for Dexterous Hand-arm Teleoperation". PhD thesis. Hamburg: Universität Hamburg, 2022

Challenges in a Hand-Arm Teleoperation (cont.)

- visual haptic feedback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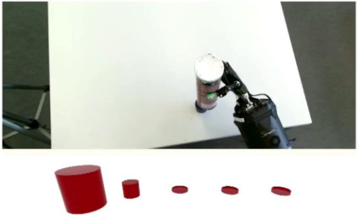
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[3] Li, "Vision-based Perception for Dexterous Hand-arm Teleoperation"

Goals

- Integration in ROS
- Possible use in vision-based teleoperation setup of Li,[4] Li et al.[5]
- Low-latency feedback
- Different feedback modes and levels
- Inexpensive materials: thin cotton glove with small vibration coin-motors

[4] Li, "Vision-based Perception for Dexterous Hand-arm Teleoperation".

[5] Shuang Li et al. "A Dexterous Hand-Arm Teleoperation System Based on Hand Pose Estimation and Active Vision". In: *IEEE Transactions on Cybernetics* (2022), pp. 1–12.

Questions regarding the haptic glove with vibration feedback

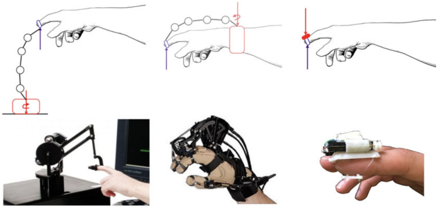
- Latency
- Reliability of perception
- Naturalness
- Differentiation capacity
- Subjective preferences for feedback types

Haptic feedback devices

Categorization [6]

- Kinesthetic systems: active/passive force-feedback
- Tactile systems
  - Contact: mechanical, electric, thermal stimulus
  - Non-Contact: ultrasonic waves

Wearability of devices[7]



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[6]Eric Vezzoli et al. *XR Haptics, Implementation and Design Guidelines*. Haptics Industry Forum, 2022

[7]Claudio Pacchierotti et al. "Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives". In: *IEEE Transactions on Haptics* 10.4 (2017), pp. 580–600

[8]ibid.

Haptic feedback devices for the hand (examples)


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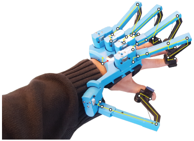
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[9] *HaptX Glove*. URL: https://haptx.com

[10] *Senceglove DK1 Exoskeleton*. URL: https://senseglove.gitlab.io/SenseGloveDocs/kinematics/dk1-kinematics.html

[11] *Dexmo Force Feedback Glove*. URL: https://www.dextarobotics.com

[12] *Virtuose™ 6D TAO*. URL: https://www.haption.com/en/products-en/virtuose-6d-tao-en.html

[13] *Ultraleap Stratos Explore*. URL: https://www.ultraleap.com/haptics/

[14] *bHaptics TactGlove*. URL: https://www.bhaptics.com/

Design considerations

Objectives for haptic simulation devices:[15]

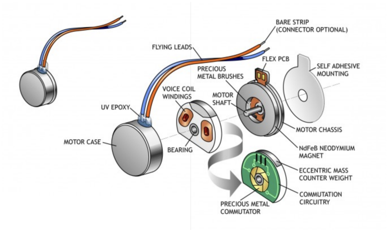
- Realism
- User experience
- Usability
- Skill transfer
- Expressivity
- Transparency

Ergonomic aspects:[16] form factor, weight, impairment, comfort

[15] Vezzoli et al., *XR Haptics, Implementation and Design Guidelines*.

[16] Pacchierotti et al., "Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives".

ERM and LRA coin motors



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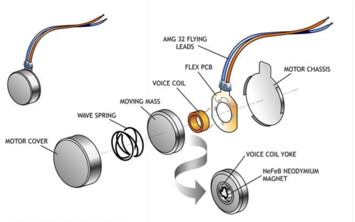

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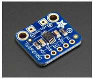
[17] *Coin Vibration Motors*. URL: https://www.precisionmicrodrives.com/coin-vibration-motors

[18] *Understanding Linear Resonant Actuator Characteristics*. URL: https://www.precisionmicrodrives.com/ab-020

Implementation of the Glove - Materials

- 8 x LRA coin motors (8 × 3.2 mm)
- DRV2605L Haptic Driver
- TCA9548A I2C Multiplexer
- Arduino Uno



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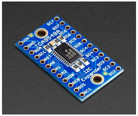

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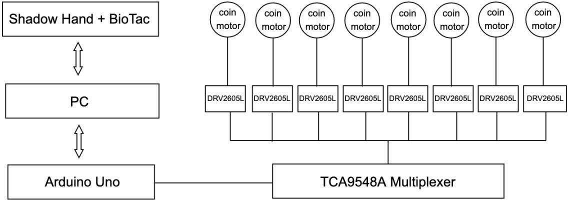

[19] *Adafruit DRV2605L Controller*. URL: https://www.berrybase.de/adafruit-drv2605l-controller-fuer-haptische-motoren

[20] *Adafruit TCA9548A I2C Multiplexer*. URL: https://www.berrybase.de/adafruit-tca9548a-i2c-multiplexer

Robot Hardware

- PR2-Robot
- Shadow Hand (5 Finger Version)
- BioTac Sensors

[21]

[21] Li, "Vision-based Perception for Dexterous Hand-arm Teleoperation"

BioTac Sensor

- Impedance
- Fluid pressure
- Microvibration
- Temperature
- Thermal flux


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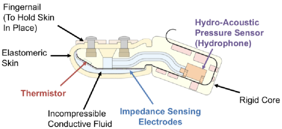

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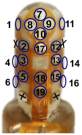

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[22] *Biotac Manual*. URL: https://syntouchinc.com/wp-content/uploads/2020/09/SynTouch-Product-Manual-BioTac-2020-09-23.pdf

[23] ibid.

[24] Yevgen Chebotar et al. "Self-supervised regrasping using spatio-temporal tactile features and reinforcement learning". In: *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2016, pp. 1960–1966

Rosbag Data Recordings

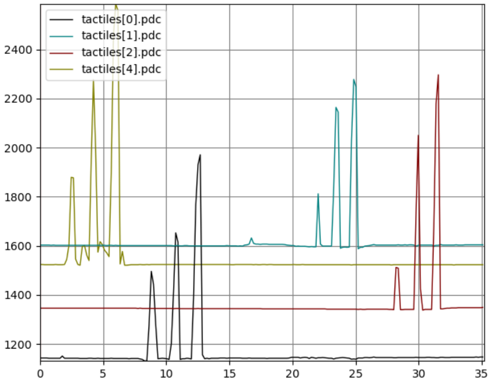


Figure: Fluid pressure (pdc) values from contacts with different strengths

Rosbag Data Recordings (cont.)

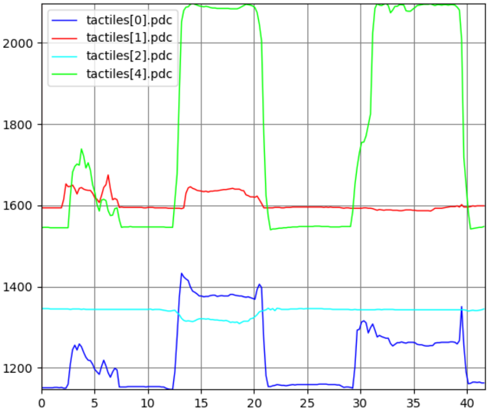


Figure: Fluid pressure (pdc) values while holding an object

Rosbag Data Recordings (cont.)

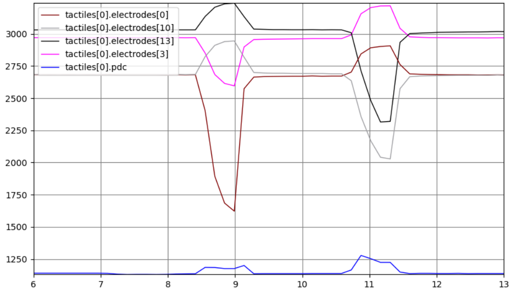
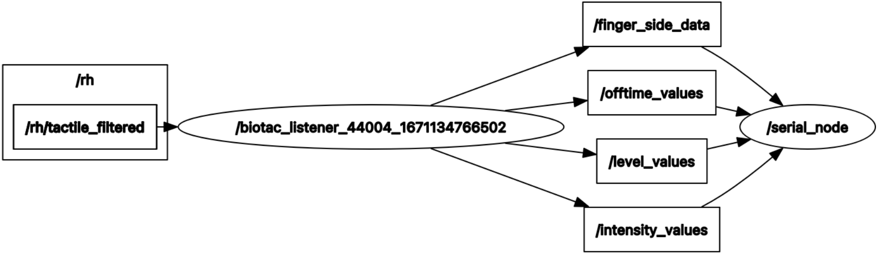


Figure: Fluid pressure (pdc) and impedance (electrodes) values while contacting the sensor from the left and right side

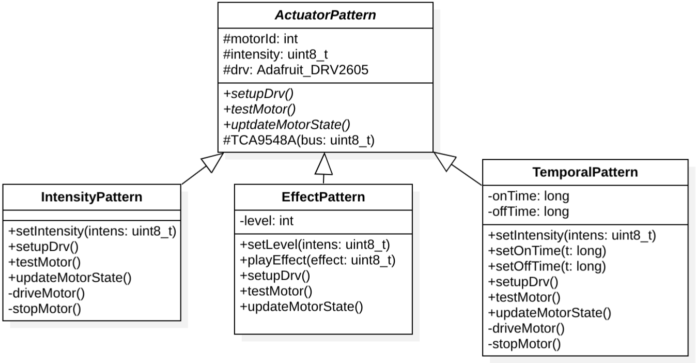
Integration in ROS

- /biotac_listener: intermediary node, subscribes for messages from BioTac and publishes data for controlling the motors
- Node on Arduino-client: subscribes for required motor control data
- /serial_node: bridge between the Arduino client and the host ROS-System (rosserial_python)



Implementation of three different Feedback Modes

1. Feedback through intensity levels
2. Feedback through waveform effects
3. Feedback through temporal patterns (intermittent signals)



1. Intensity levels Feedback

- Different vibration-amplitudes at certain levels of contact pressure
- “Realtime Playback Mode” of DRV2605L Driver
- Motor amplitude value range: 0-127

Pdc change	**Amplitude (intensity) value**
=<50	no feedback
51-100	10
101-200	20
201-300	40
301-500	70
>500	127

2. Effect waveform Feedback

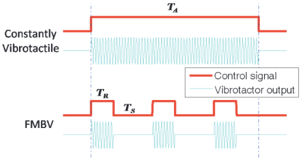
- Different types/numbers of effects at certain thresholds of contact pressure
- Internal waveform library of DRV2605L Driver
- Distinct signal for first contact

Pdc change (thresholds)	**Effects (repetitions)**
51	1 x “transition click”
151	2 x “strong click”
301	3 x “strong click”
601	4 x “strong click”

2. Temporal Feedback

- Different waveform frequencies at certain levels of contact pressure
- "Realtime Playback Mode" with constant amplitude
- On-time: 200 ms, off-time: 20 - 480 ms

Pdc change	Off-time value (ms)
=<50	no feedback
51-100	480
101-200	240
201-300	120
301-500	60
>500	20



[25]

[25] Ryad Chellali and Huynh-Phong Pham. "Frequency modulation based vibrotactile feedback vs visual feedback in a multimodal interface for 3D pointing tasks in teleoperation". In: *2011 IEEE International Conference on Robotics and Biomimetics*. 2011, pp. 14–19

Summary

- Integration with low feedback latency
- Discrimination between levels
- Temporal feedback seems most effective
- Different feedback modes could be helpful for different types of interaction scenarios
- Possible integration in a teleoperation setup in future

Outlook

- Use of better materials, technical components
- Contact between motor and skin could be improved
- Possibility of using different types of feedback at different stages of interaction with an object
- Wireless connection

Thank you for your attention!

References

- *Adafruit DRV2605L Controller*. URL: https://www.berrybase.de/adafruit-drv2605l-controller-fuer-haptische-motoren.
- *Adafruit TCA9548A I2C Multiplexer*. URL: https://www.berrybase.de/adafruit-tca9548a-i2c-multiplexer.
- *bHaptics TactGlove*. URL: https://www.bhaptics.com/.
- *Biotac Manual*. URL: https://syntouchinc.com/wp-content/uploads/2020/09/SynTouch-Product-Manual-BioTac-2020-09-23.pdf.

Chebotar, Yevgen, Karol Hausman, Zhe Su, Gaurav S. Sukhatme, and Stefan Schaal. “Self-supervised regrasping using spatio-temporal tactile features and reinforcement learning”. In: *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2016, pp. 1960–1966.

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Li, Shuang. “Vision-based Perception for Dexterous Hand-arm Teleoperation”. PhD thesis. Hamburg: Universität Hamburg, 2022.

Li, Shuang, Norman Hendrich, Hongzhuo Liang, Philipp Ruppel, Changshui Zhang, and Jianwei Zhang. “A Dexterous Hand-Arm Teleoperation System Based on Hand Pose Estimation and Active Vision”. In: *IEEE Transactions on Cybernetics* (2022), pp. 1–12.

Pacchierotti, Claudio, Stephen Sinclair, Massimiliano Solazzi, Antonio Frisoli, Vincent Hayward, and Domenico Prattichizzo. “Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives”. In: *IEEE Transactions on Haptics* 10.4 (2017), pp. 580–600.

Senceglove DK1 Exoskeleton. URL: https://senseglove.gitlab.io/SenseGloveDocs/kinematics/dk1-kinematics.html.

SynTouch Biotac. URL: https://syntouchinc.com/.

- *Ultraleap Stratos Explore*. URL: https://www.ultraleap.com/haptics/.
- *Understanding Linear Resonant Actuator Characteristics*. URL: https://www.precisionmicrodrives.com/ab-020.
- Vezzoli, Eric, Chris Ulrich, Gijs den Butter, Rafal Pijewski, and Vincent Hayward. *XR Haptics, Implementation and Design Guidelines*. Haptics Industry Forum, 2022.
- *Virtuose™ 6D TAO*. URL: https://www.haption.com/en/products-en/virtuose-6d-tao-en.html.