Universität Bielefeld Center of Excellence Cognitive Interaction Technology

CITEC

Tactile Perception for Autonomous Grasping and in Cars

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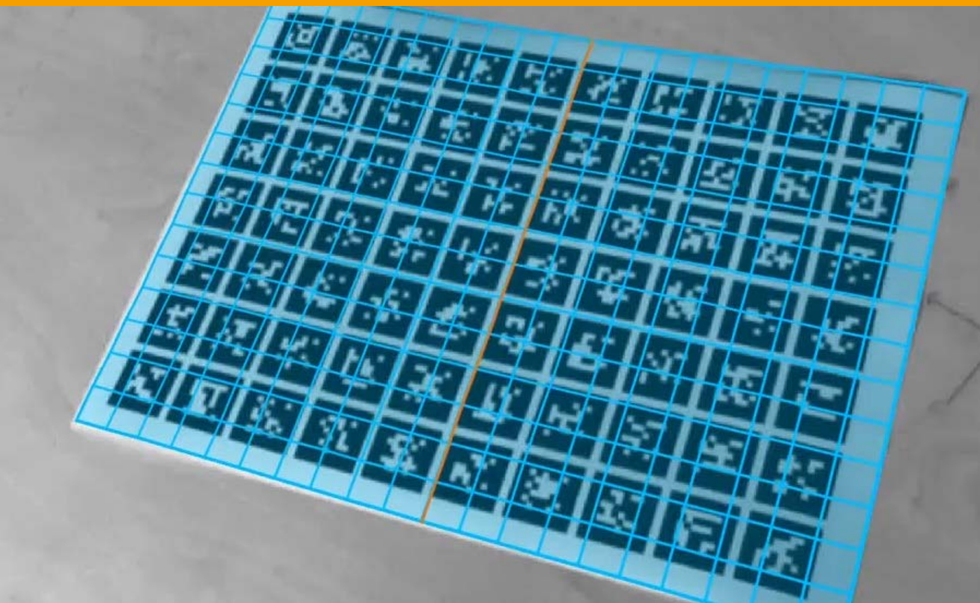
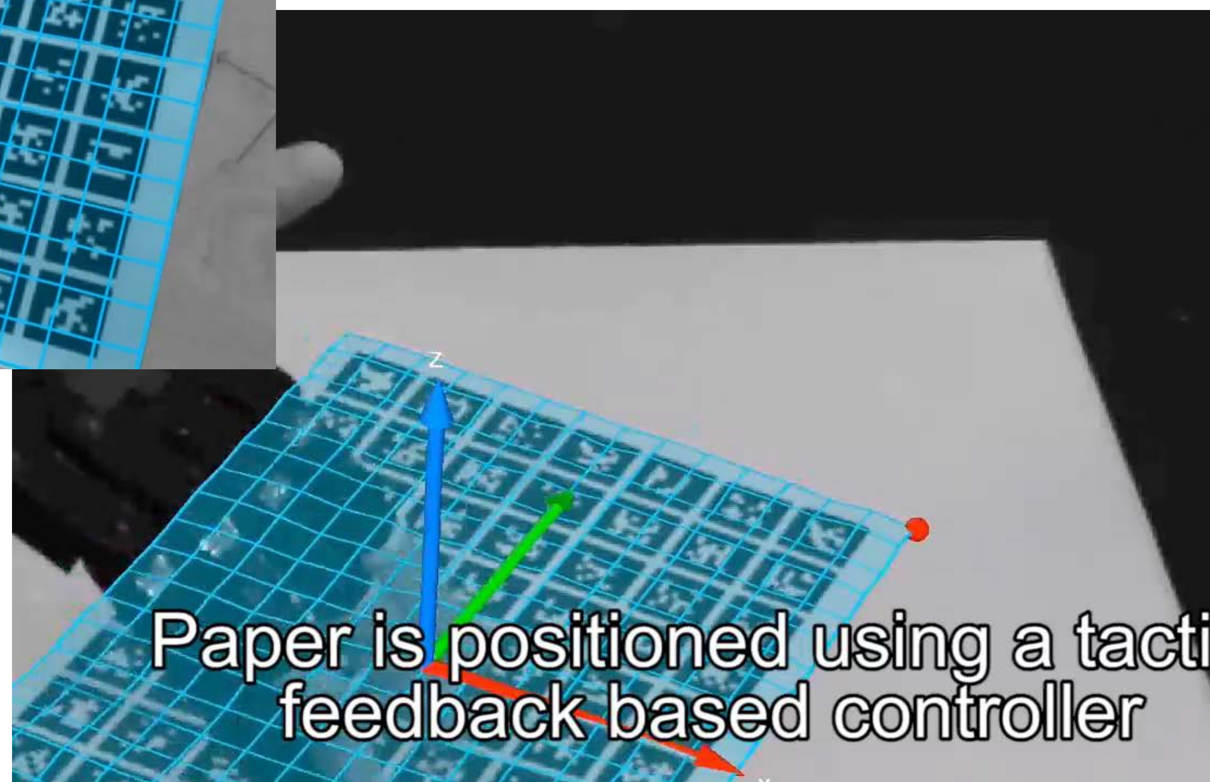
Background: Understand + Replicate Manual Intelligence



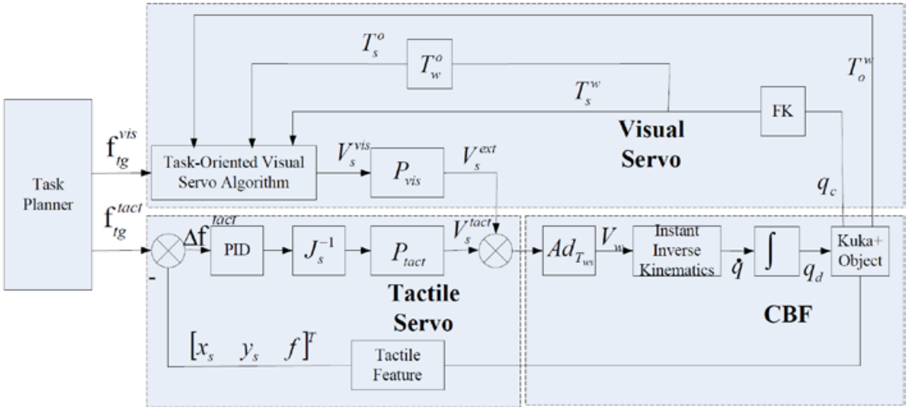


Elbrechter et al: Folding Paper with Anthropomorphic Robot Hands using Real-Time Physics-Based Modelling (Humanoids 2012)

Classical Engineering vs. Deep-Learning

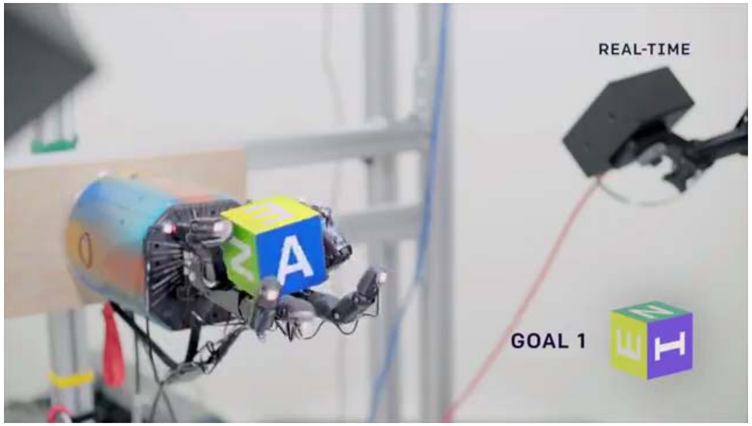
Classical Control Engineering

- Great results when world is correctly modelled
- No generalization beyond model
- Human-time intensive



End-to-End Learning

- Indispensable when modelling is hard or infeasible
- Generalization within training domain
- Machine-time intensive



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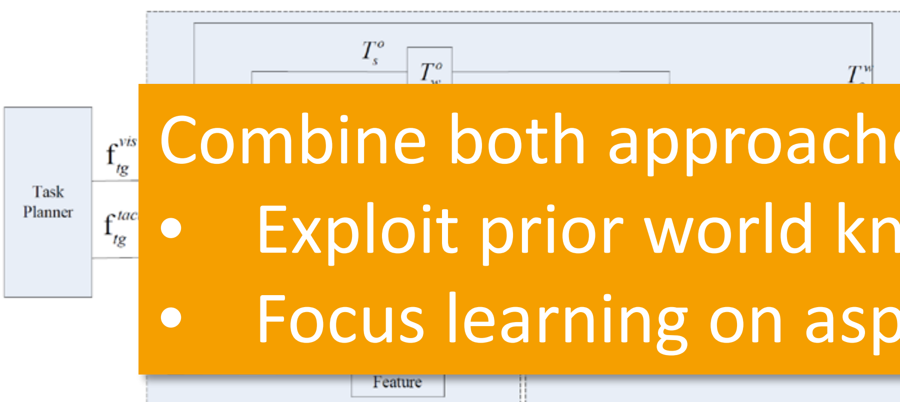
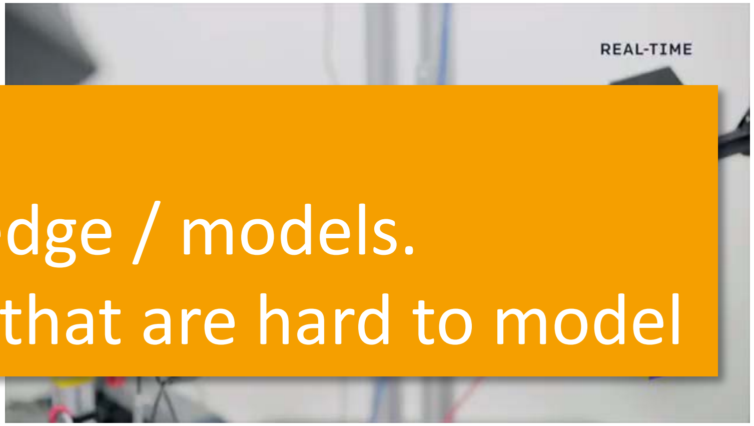
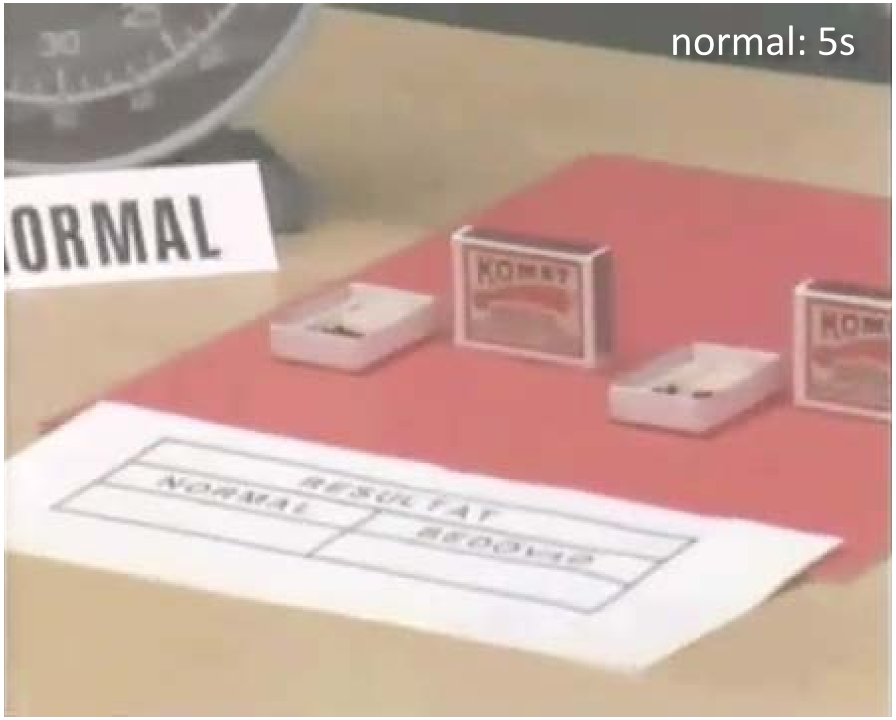




Combine both approaches!

- Exploit prior world knowledge / models.
- Focus learning on aspects that are hard to model

Importance of tactile and visual feedback



Prof. Roland Johansson, Dept. of Physiology, University of Umeå, Sweden

Tactile Sensors for Manipulation

- How can we utilize tactile sensors
  - for handover?
  - to detect dropping of objects?
  - to detect incipient slippage?
  - to detect unintended contact?
  - explore object surfaces?
- What are required specs w.r.t.
  - spatial resolution?
  - temporal resolution?
  - sensitivity?
  - force range?

Incipient Slip Detection + Grasp Force Adaptation

- Incipient slippage generates micro vibrations in ~400 Hz range
- … amplified by human fingerprints
- calls for fast tactile sensors

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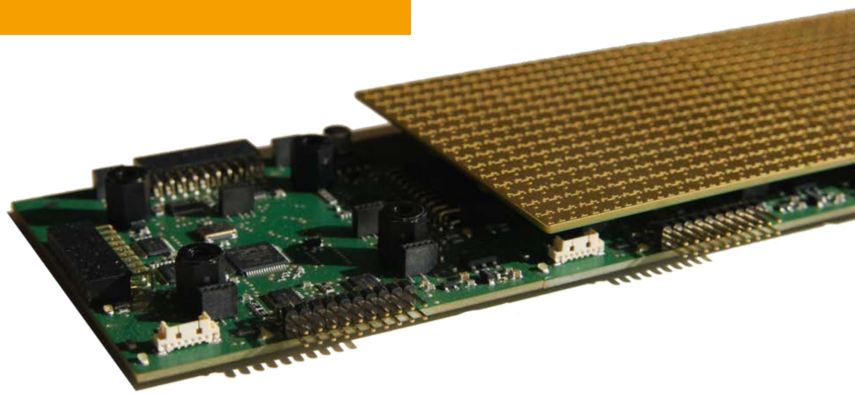
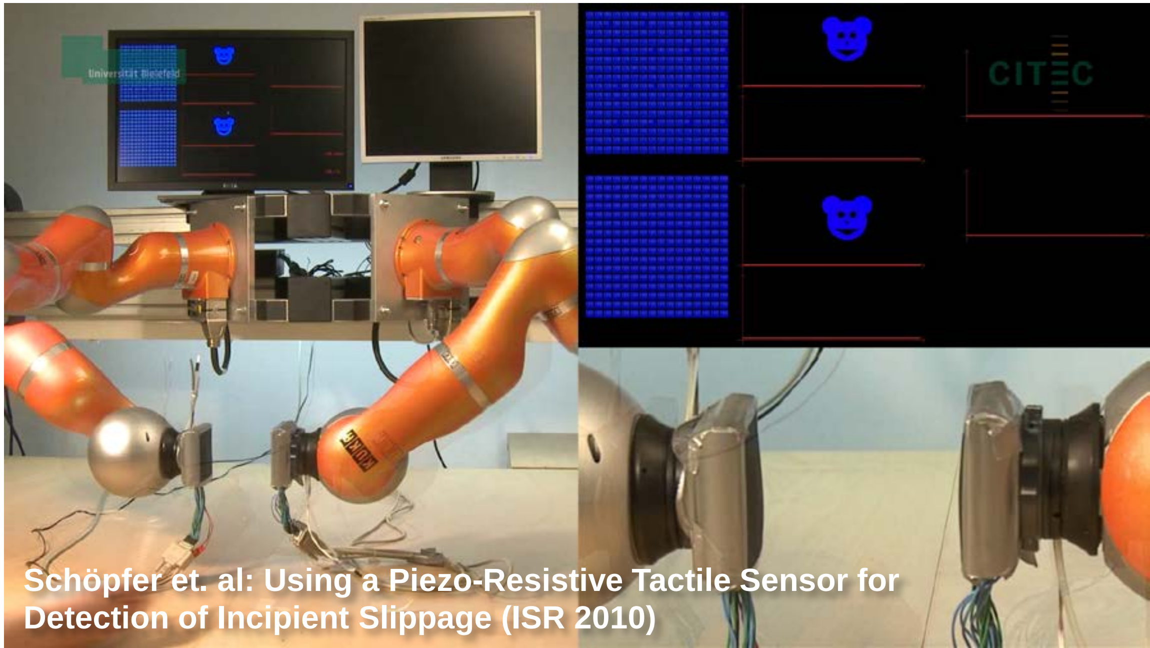


- 16x16 tactile array
- ≈2kHz frame rate

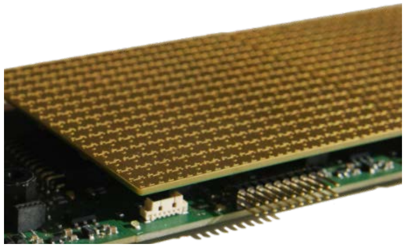
- train a neural network to classify slippage
- increase grasping force on slippage

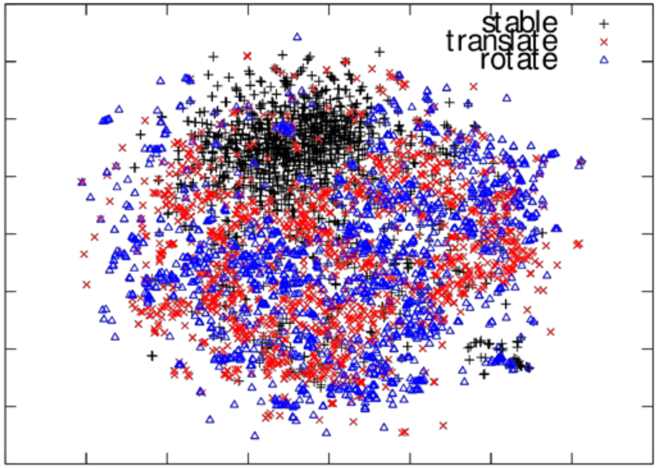


Schöpfer et. al: Using a Piezo-Resistive Tactile Sensor for Detection of Incipient Slippage (ISR 2010)

Incipient Slip Detection: Going more complex

- Basic slip detection is simple
- What about different types of slippage?
  - stable – translational– rotational
- Sensor array vs. small finger tip?

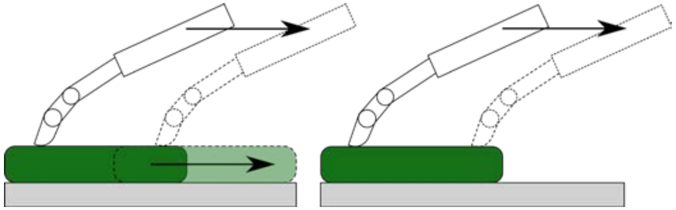




t-SNE embeddings of input

Incipient Slip Detection: Going more complex

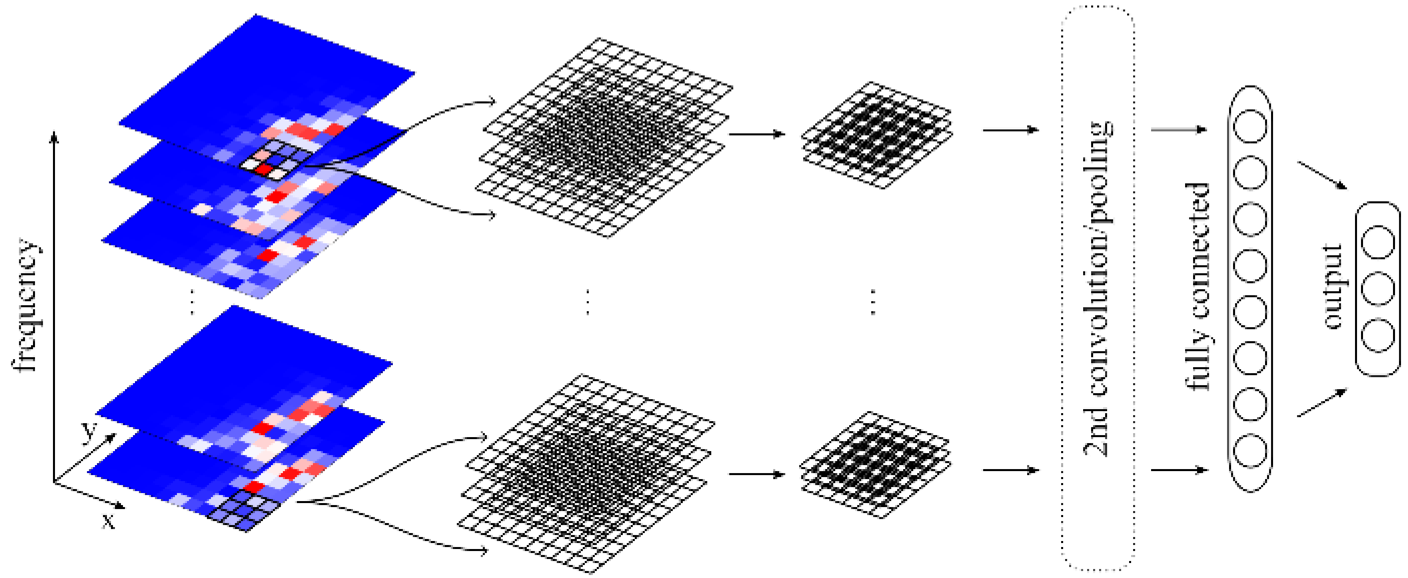
- Basic slip detection is simple
- What about different types of slipp
  - stable – linear – rotatory
- Sensor array vs. small finger tip?
- Object sliding vs. slipping



t-SNE embeddings of input

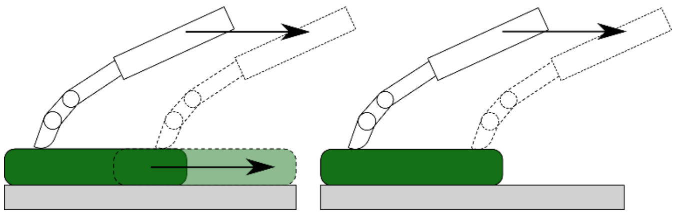
Deep Convolutional Neural Network for Slip Detection

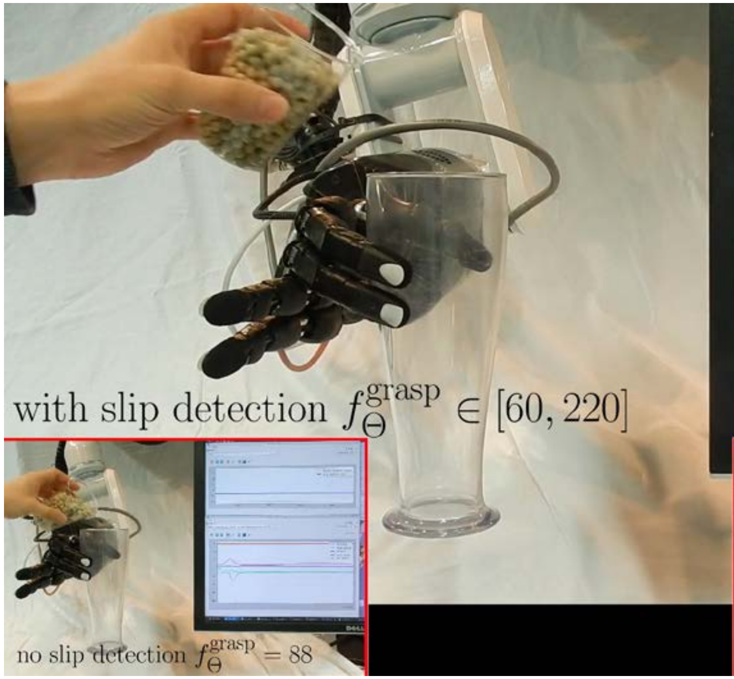
- Fourier analysis for individual taxels
  - spatially arranged in taxel grid
- learn convolutional filter (3x3) per frequency layer
- 2x2 pooling
- fully-connected classification layer



Results

- Different *types* of slip — **97.8%**
  - static
  - translational
  - rotational
- Slip Detection on Fingertips — **96.4%**
- „Sliding with“ vs. „Sliding on“ an object — **81.9%** vs. **73.3%** (MLP)

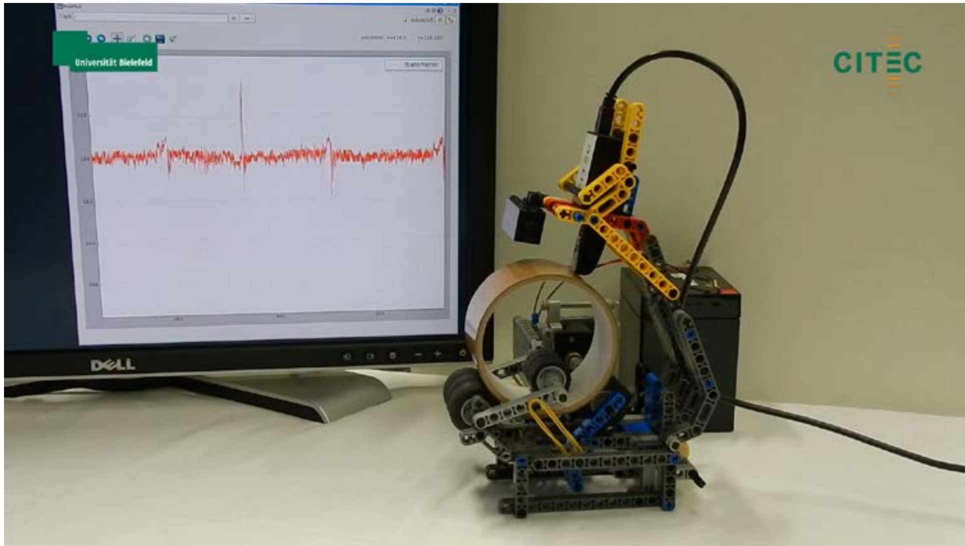




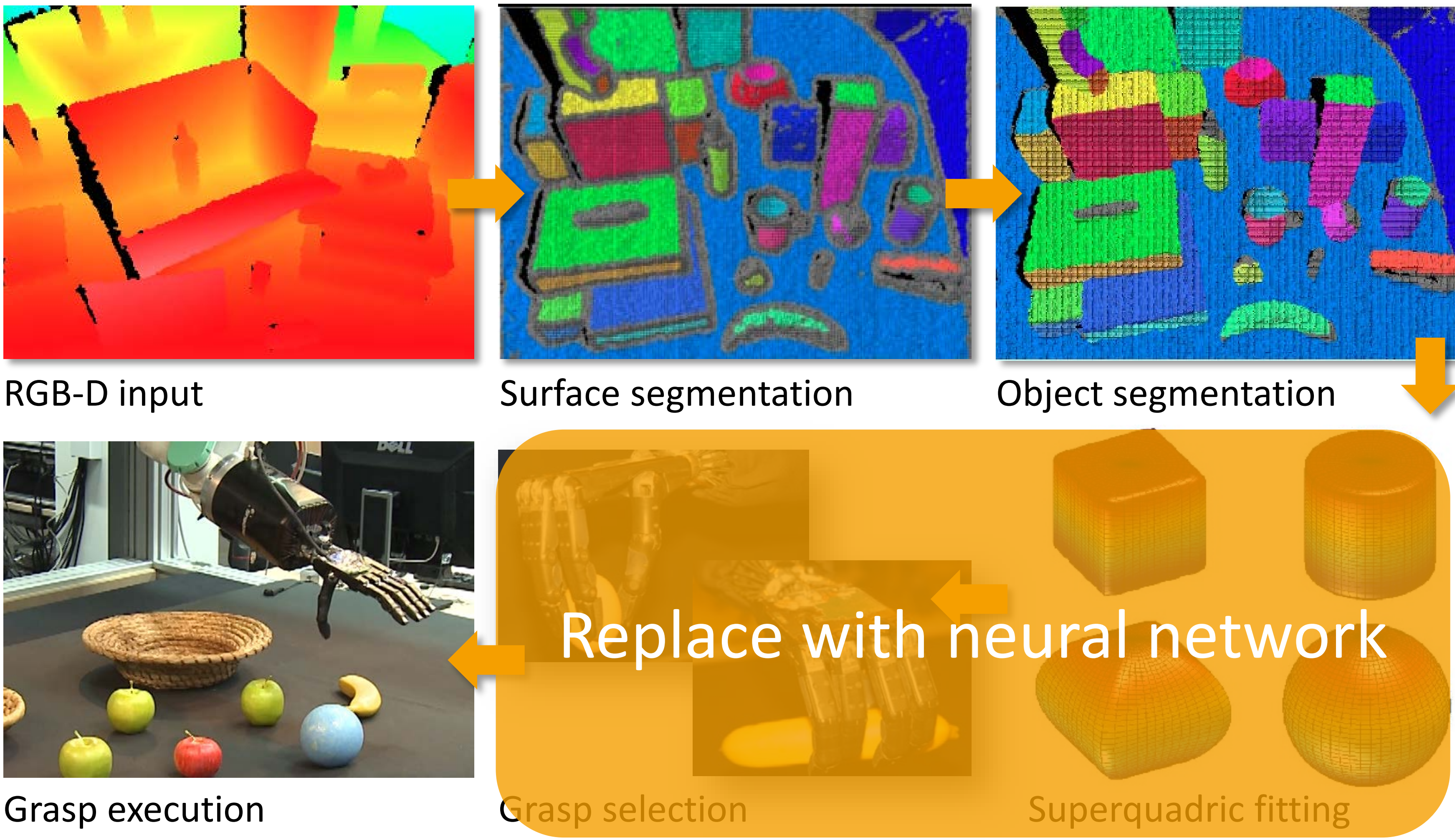
Sensorized Fingernail

- nail important for:
  - grasping tiny objects
  - texture recognition
- 3-axes force sensor
  - lateral forces
    hall sensors
  - normal force
    barometer sensor
    sensitivity: ≈6mN
- example application
  - detect end of tape

Koiva et al. IROS 2018



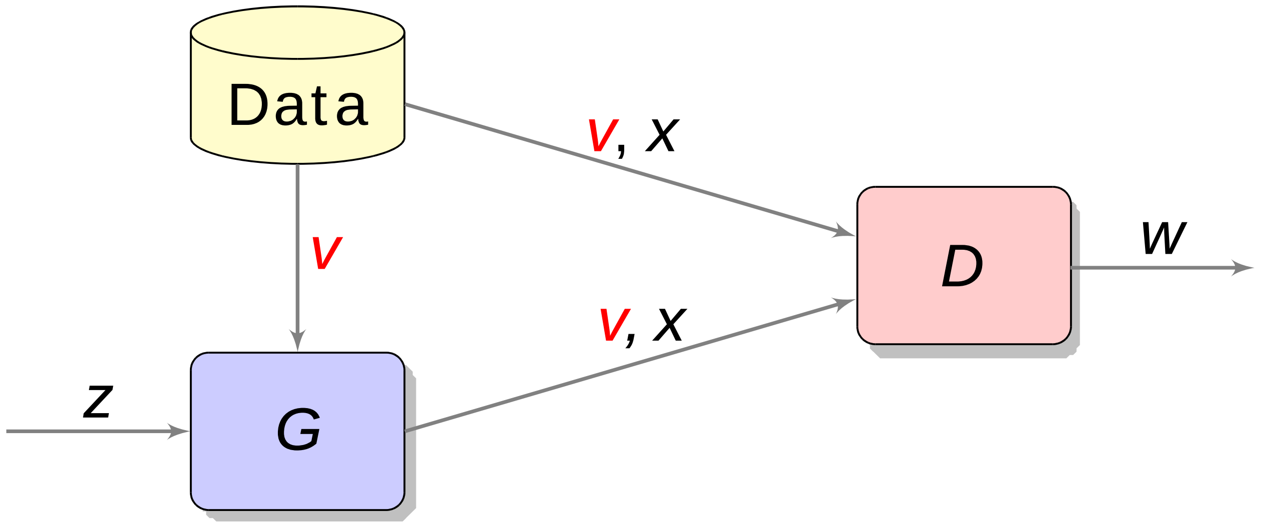
Learning Grasps from Depth Images



Learning Grasps from Depth Images

- Conditional Wasserstein GAN
- Generative model

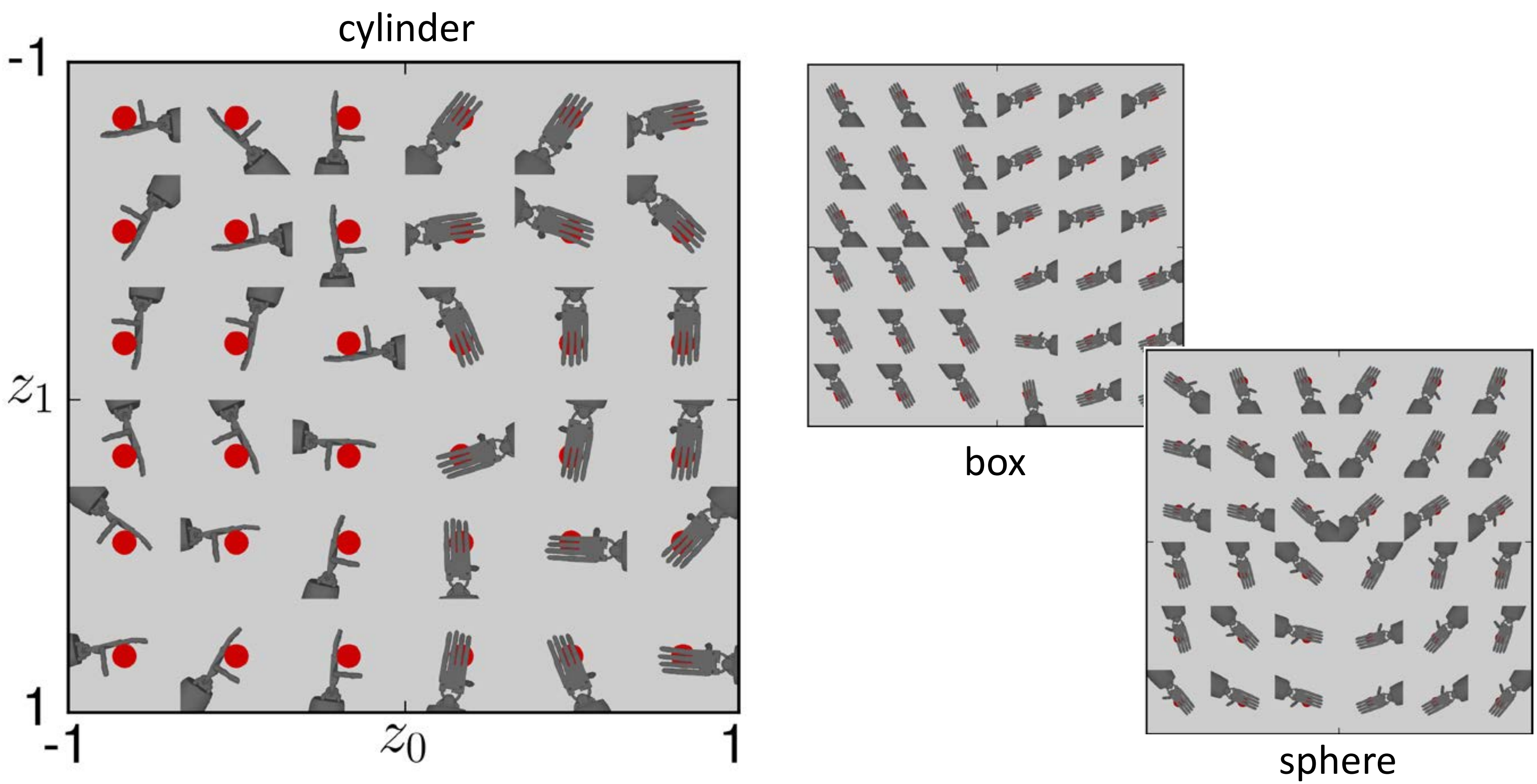
G: grasp generator
D: discriminator
v: depth image
x: grasp
z: random variable



$$\min_{D} \max_{G} \mathbb{E}_{\mathbf{v} \sim P_v} \left(\mathbb{E}_{\tilde{\mathbf{x}} \in p_{\tilde{x}}(\mathbf{v})} [D(\tilde{\mathbf{x}}, \mathbf{v})] - \mathbb{E}_{\mathbf{x} \in p_x(\mathbf{v})} [D(\mathbf{x}, \mathbf{v})] \right)$$

Learning Grasps from Depth Images: Result

- Latent space exhibits nice, self-emerging structure



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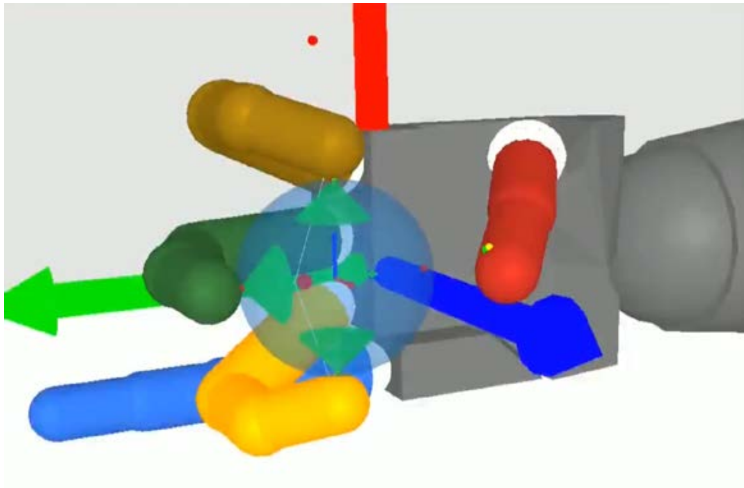
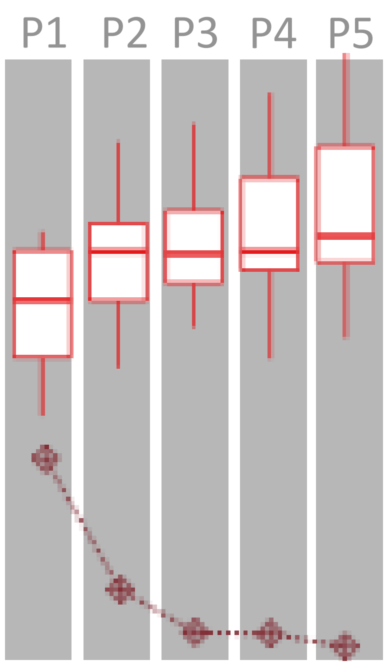
Tactile Servoing

- use tactile features directly for EE control
- **contact force** error mapped onto
  ⇨ normal motion
- **contact position** error mapped onto
  ⇨ tangential motion
  ⇨ rolling/tilting motion
- **axis orientation** error mapped onto
  ⇨ rotation around normal axis
- external motion component generates exploratory behaviour



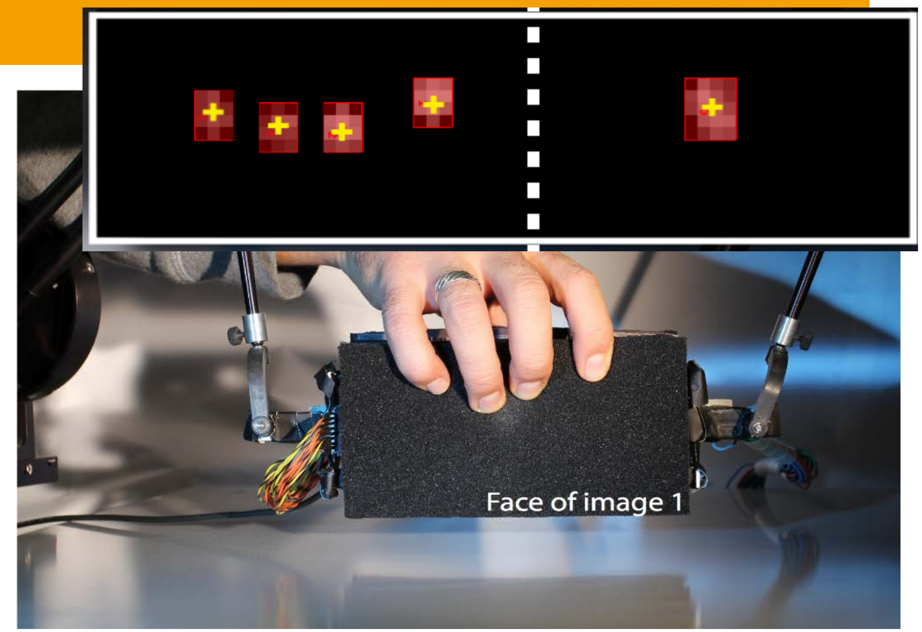
Sensorized Objects for Human Manipulation Research

- **„Tactile Object (TACO)“**
  - book-like object
  - 2x2 sensor arrays á 16x16



grip force

pose deviation

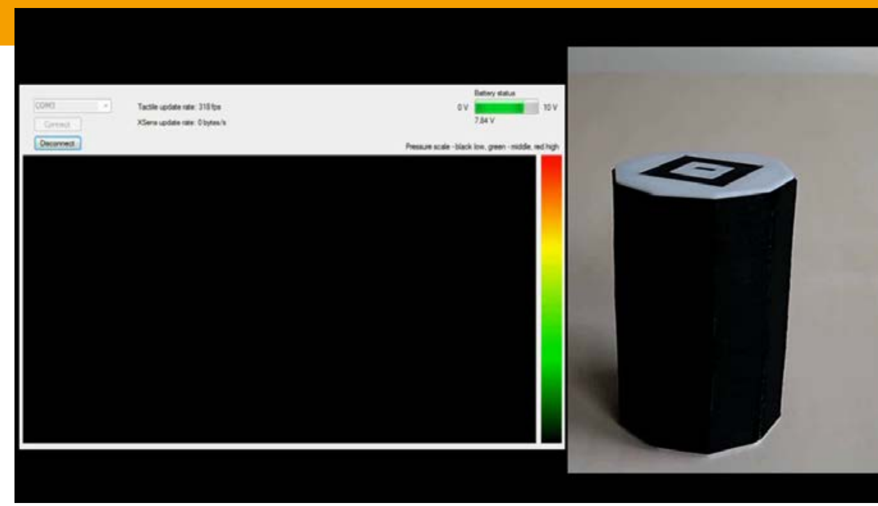


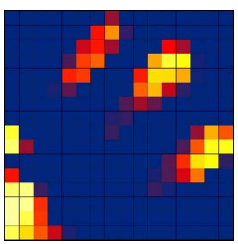
When perturbed, humans quickly adapt and stiffen the grasp in a synergistic fashion.

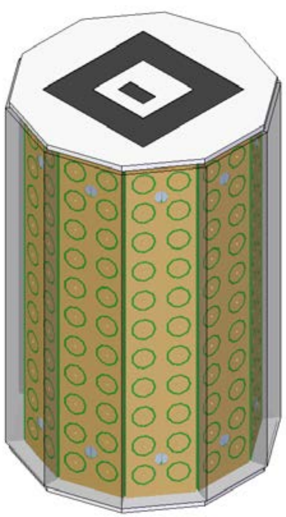
Naceri et al. J. Neurophysiology 2017

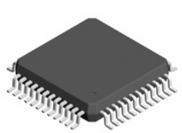
Sensorized Objects for Human Manipulation Research

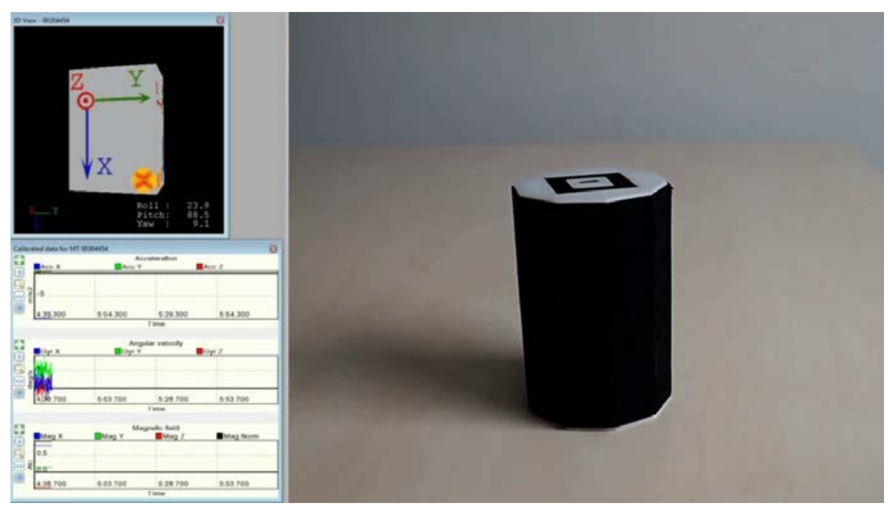
- **Tactile Can**
  - 10 strips of sensor arrays á 2x10
  - motion sensor
  - various tools











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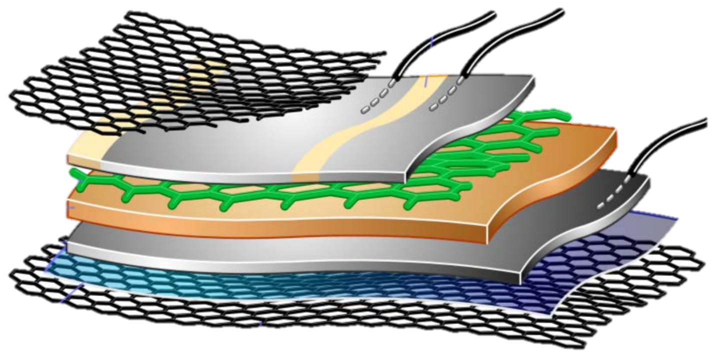
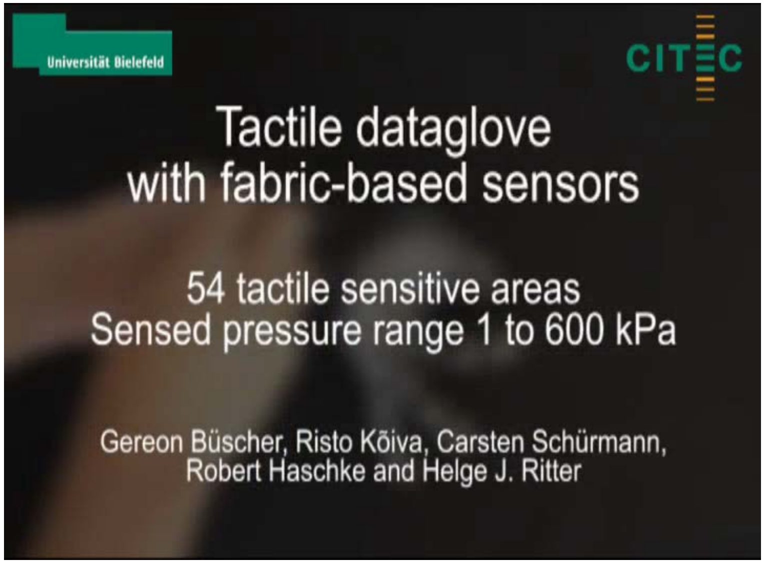
Tactile Data-Glove for Human Manipulation Research

Büscher et al. Tactile dataglove with fabric-based sensors (Humanoids 2012)





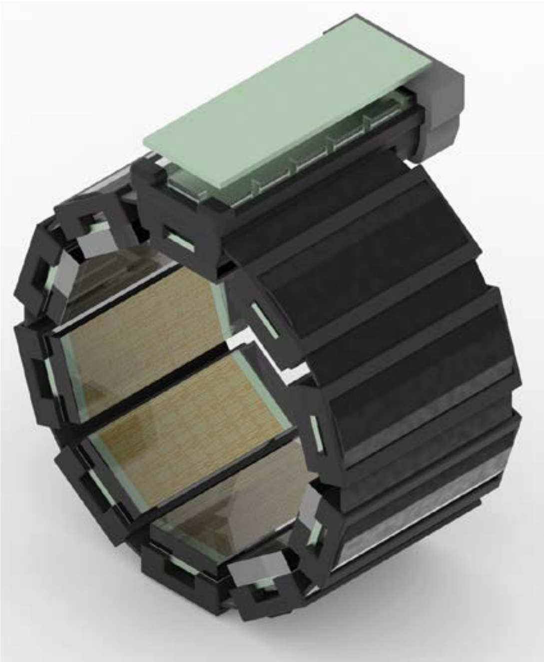
Tactile Sensors for Hand Prostheses

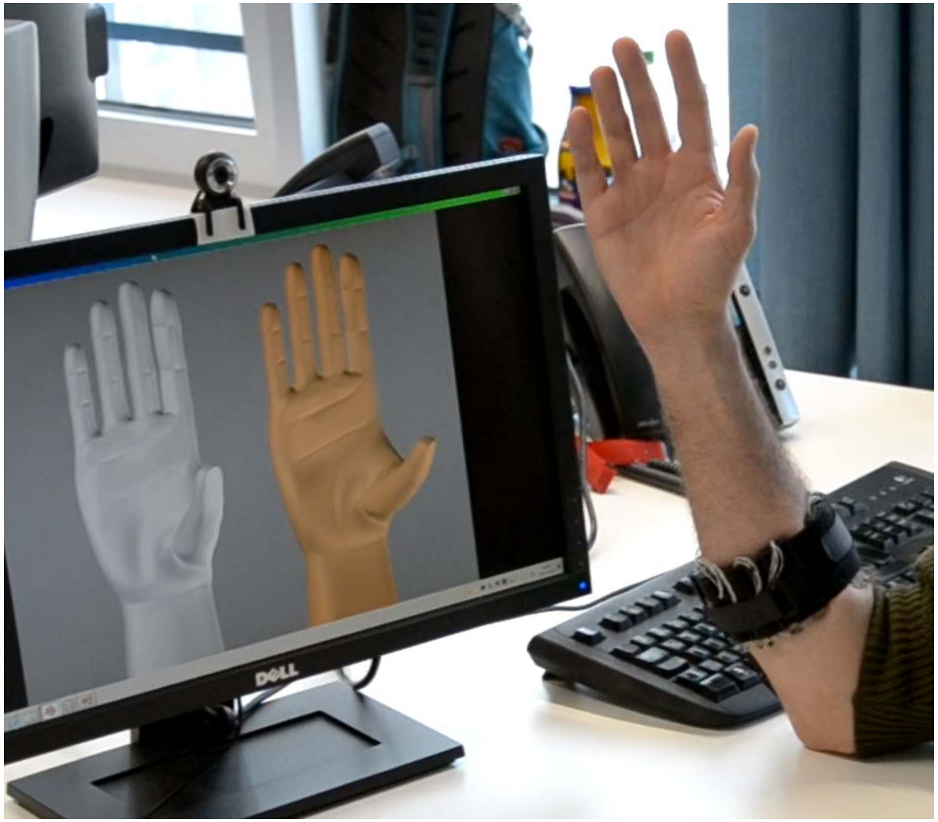
- Instrument phalanges of iLimb prosthetic hand
- sealed by silicon wrapping
- to be slipped on iLimb bones

- deep neural network applications
  - slip detection: LSTM, 92% acc.
  - stiffness classification: LSTM correlating hand-closing profile to tactile forces

Tactile-Based Prosthesis Control

- Replace EMG sensors with taxel array arranged as bracelet
- Measure muscle bulgings
  - 10x 4x8 taxel arrays





Tactile pen for therapy

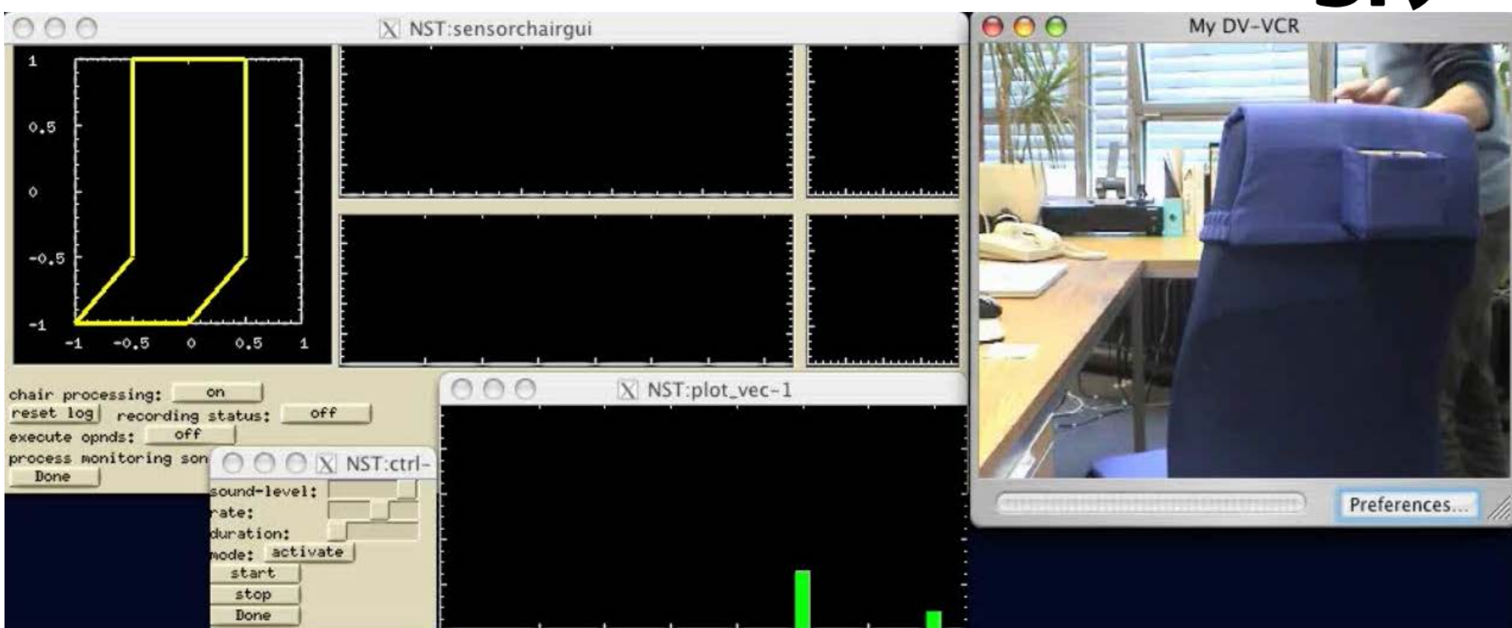
- Bad handwriting caused by bad hand posture and too high forces
- Measure applied forces
- and provide feedback

Tactile pen prototype using fabric-based sensors

Tactile Applications in Intelligent Cars?

- Monitor sitting pose of driver
  - adjust seat w/o knobs
  - monitor driver‘s attention
- „SonicChair“: sonified bio-feedback for sitting pose

Sonic Interaction Design



Summary

- Combine classical engineering approaches with learning
- Exploit prior knowledge whereever possible to facilitate learning

- Tactile sensing is key for manipulation
- … but has numerous applications beyond

Acknowledgements

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