Master thesis

Magnetic Human Hand Motion Reconstruction

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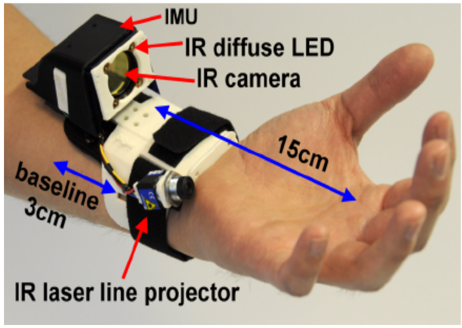
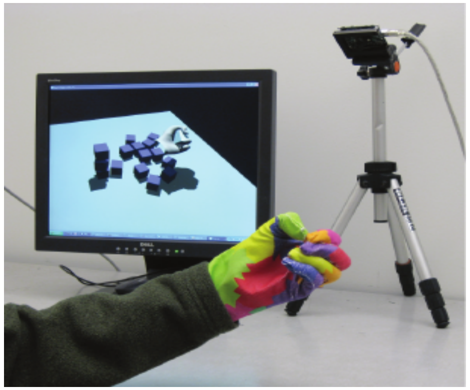
Systems for Hand Motion Reconstruction
Vision based

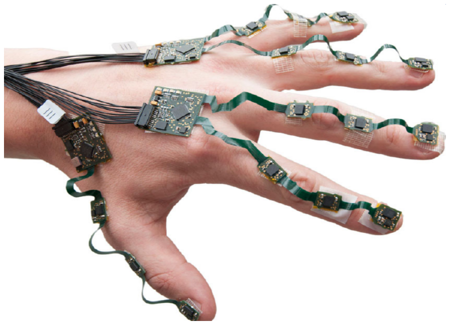
- High accuracy possible, often used as ground truth
- Usually big and static systems
- Price and number of cameras rises with demanded accuracy [1, 2]

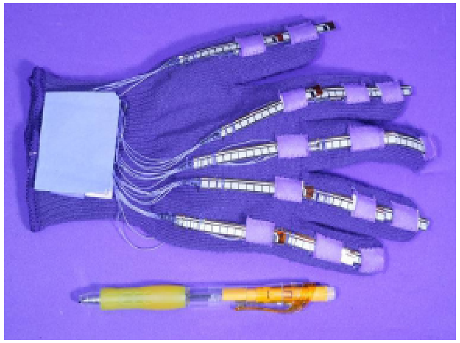




Systems for Hand Motion Reconstruction
Data gloves

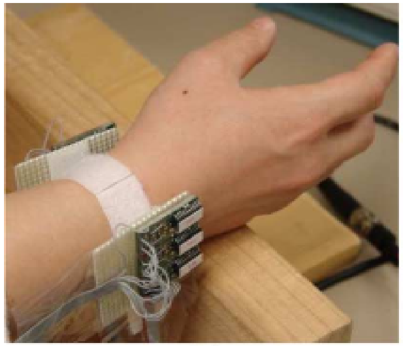
- Mobile system
- IMUs or bend sensors used
- Accuracy is dependent on number of utilized sensor units [3]
- Placement of sensors is crucial
- Average error to vision based system around 7.1° [4]





Systems for Hand Motion Reconstruction
Magnetic approach

- Passive magnetic system using magnets on fingertips [6]
  → Few publications on this



Systems for Hand Motion Reconstruction

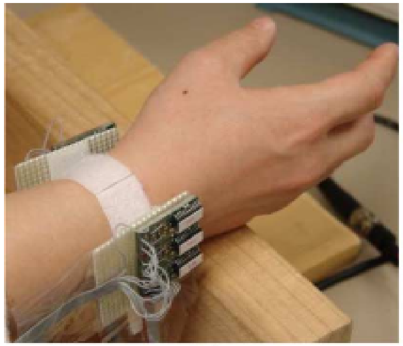
Magnetic approach

- Passive magnetic system using magnets on fingertips [6]

  → Few publications on this

  → Promising approach to build a system which is:

  - Wearable
  - Cheap
  - Easy to use

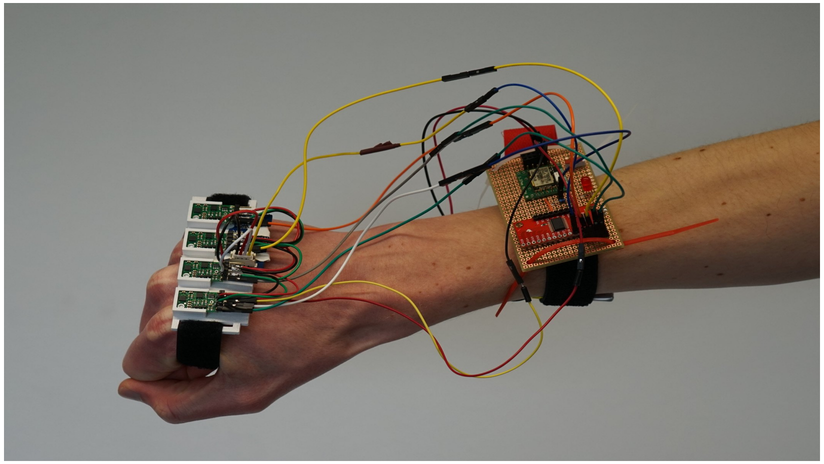


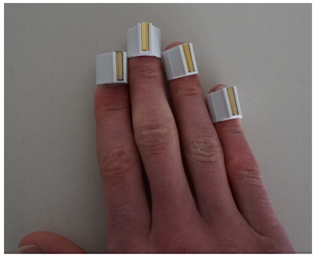
Passive Magnetic Hand Motion Reconstruction

- Finger postures are determined by joint angles
- Minimizing a nonlinear objective function for estimating *K* fingers with *N* magnets

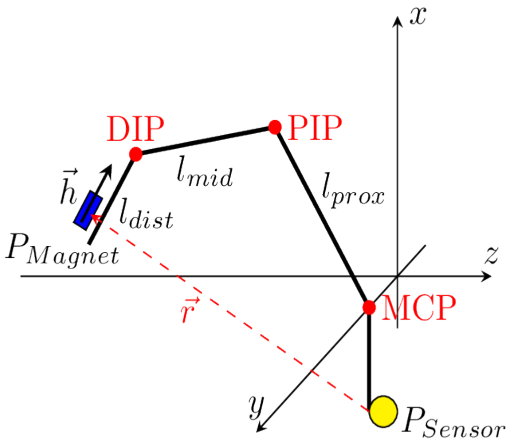
$$\underset{\mathrm{X}_K}{\text{minimize}}\ \frac{1}{2}||\tilde{\mathrm{M}} - \mathrm{M}(\mathrm{X}_K)||_2^2$$

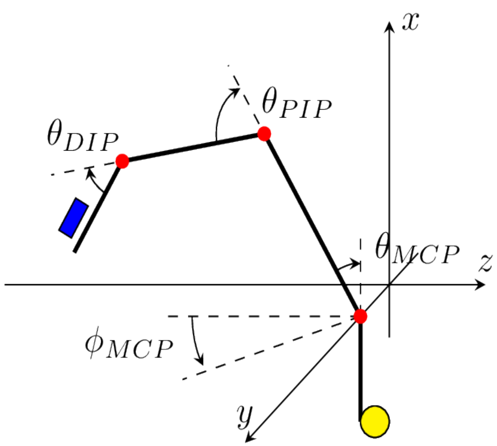
With $\tilde{\mathrm{M}}$: sensor measurements
$\mathrm{M}(\mathrm{X}_K)$: magnetic flux density for system state X_K





Modeling the Human Hand





- Position and orientation of magnet relative to sensor unit is given by the joint angles of the kinematic chain
  → Exact determination of hand dimensions is important!

- Anatomics constrain range of motion and set θ_{DIP} and θ_{PIP} into relation [7, 8]
  → (single) Finger state vector $x = \left[\theta_{\text{MCP}}\ \theta_{\text{PIP}}\ \phi_{\text{MCP}}\right]^T$
  → State vector size for estimating *K* fingers $size(\mathrm{X}_K) = (3 \times K)$

Modeling the static magnets

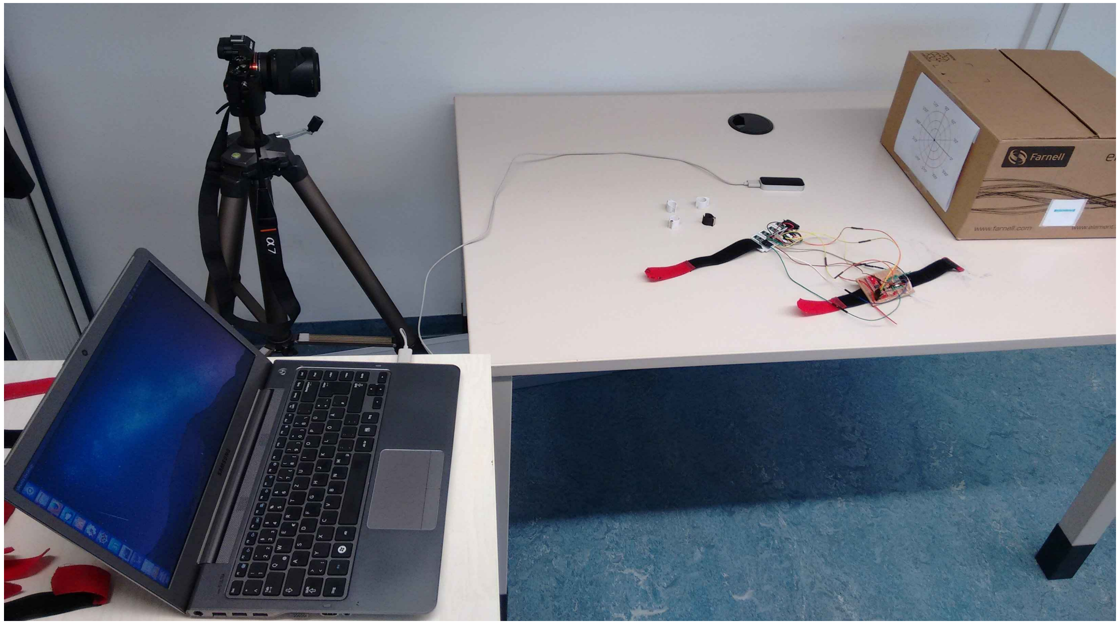
- Calculation of magnetic flux density by **cylindrical** model (numerical) [9]
- M is a cumulative sum over the *K* magnets for each of the *N* sensors

$$\mathrm{M} \equiv \begin{bmatrix} \mathrm{B}_1 & \mathrm{B}_2 & \cdots & \mathrm{B}_N \end{bmatrix}^T = \begin{bmatrix} \sum_{k=1}^{K} \mathrm{B}_1(x_k) \\ \sum_{k=1}^{K} \mathrm{B}_2(x_k) \\ \vdots \\ \sum_{k=1}^{K} \mathrm{B}_N(x_k) \end{bmatrix} = \mathrm{M}(\mathrm{X}_K)$$

- Size of M: $size(\mathrm{M}) = (3 \times N)$

- Nonlinearities introduced by position/orientation determination and magnetic models
- To get a fully determined system and unique solutions: $N \geq K$

Evaluation of the System



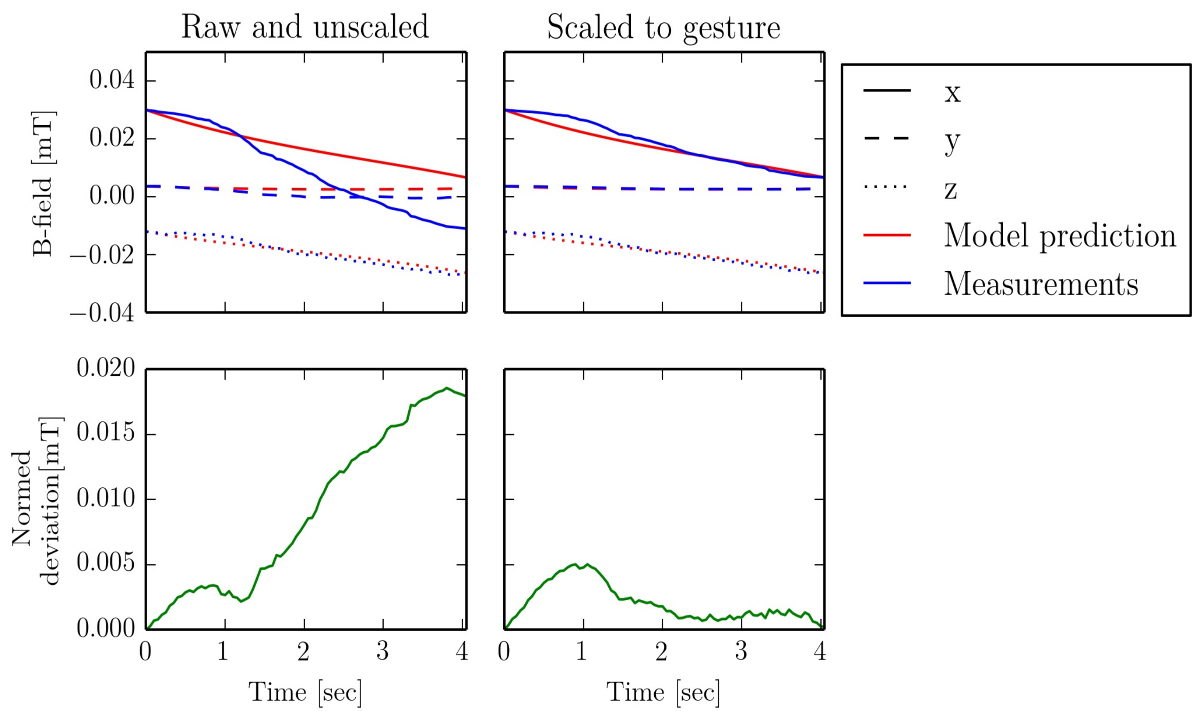
- Comparison to vision based system (Leap Motion)
- Post processing of recorded magnetic data for comparing different minimization formulations

Results

Preliminary – Scaling the measurements

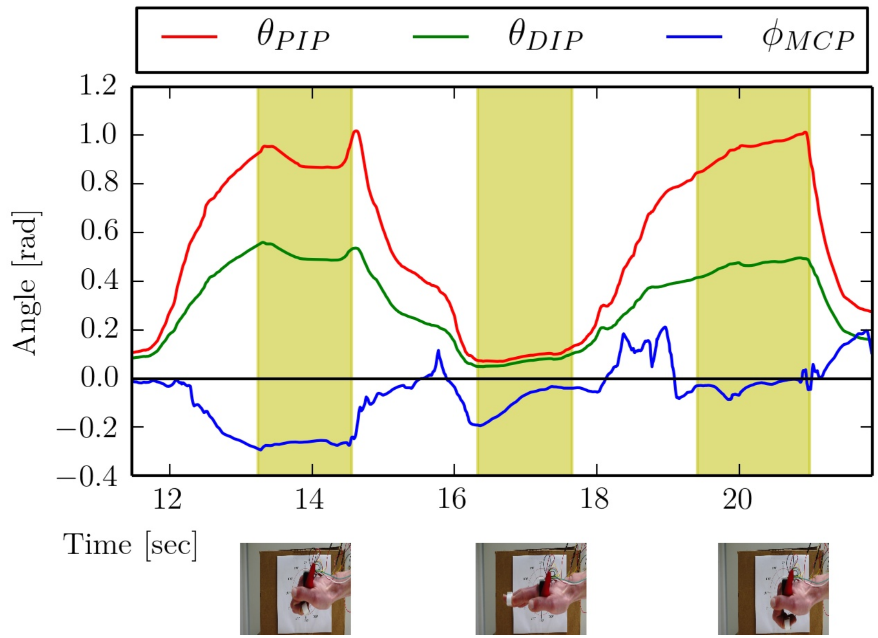
- High difference between model prediction and measurements
  → Induced by hand measured anatomic parameters
- For estimating 1 finger with 1 sensor already 9 values have to be determined
  → Estimation and tuning by trial-and-error not applicable
  → Linear scaling of measurements to model prediction leads to reasonable results

- Max deviation unscaled: $0.018\mathrm{mT}$
- Max deviation scaled: $0.005\mathrm{mT}$



Results

Preliminary – Characteristics of Leap Motion



- Minimum $\phi_{\mathrm{MCP}} = -16.845°$
- Maximum $\phi_{\mathrm{MCP}} = 12.147°$

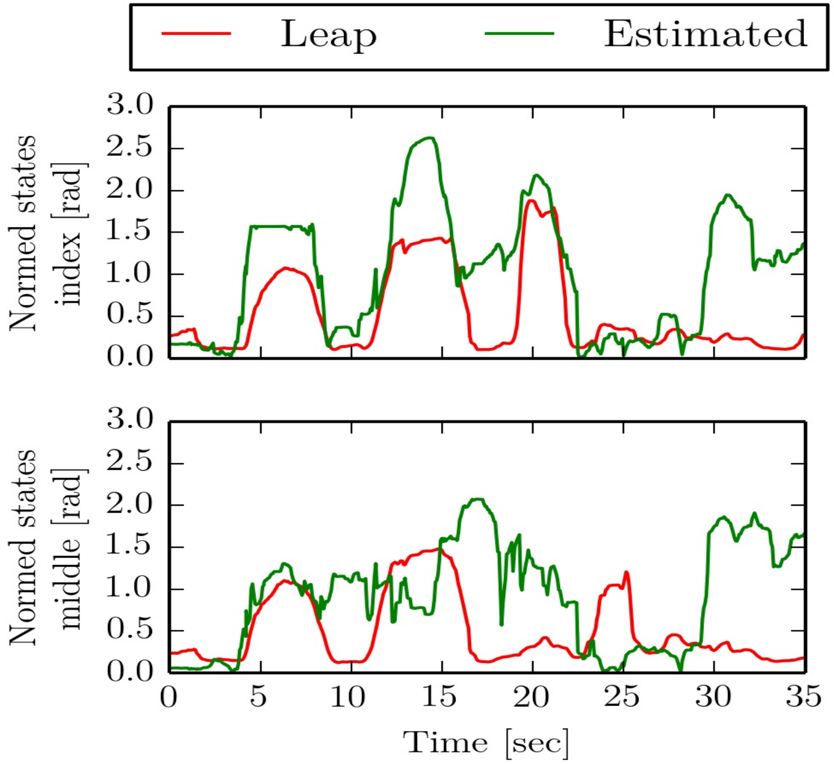
- Often false interpretation of lateral movement, which did not occur

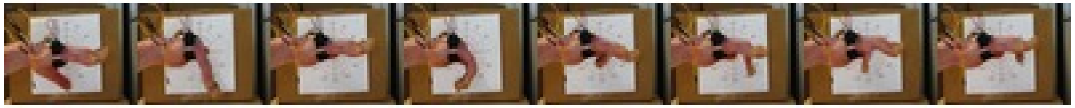
  → Possibly introduced by direction estimation of Leap

  → Lateral movement of Leap has to be handled with care

Results

Estimating four fingers





- Individual movements not detectable by magnetic system with this configuration due to:

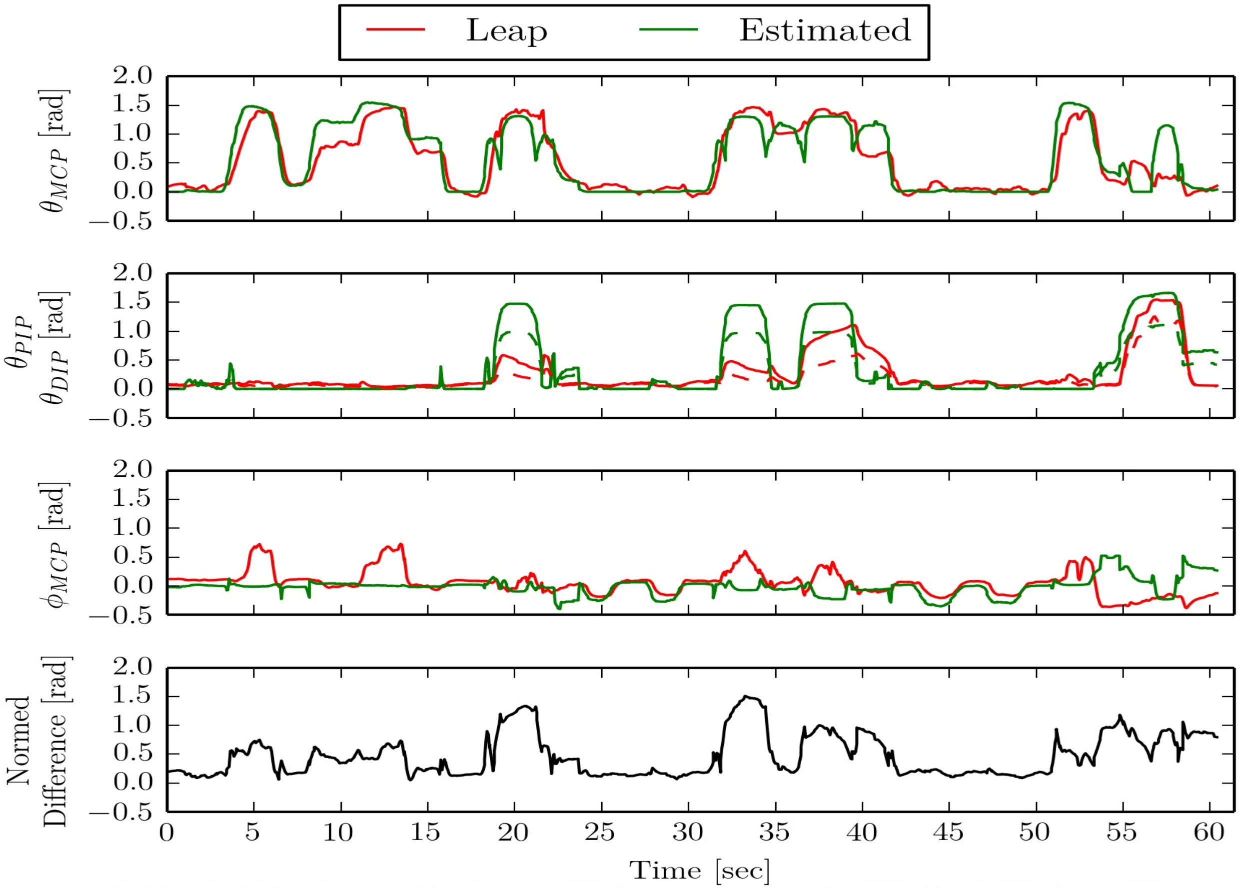
  → False measured hand dimensions

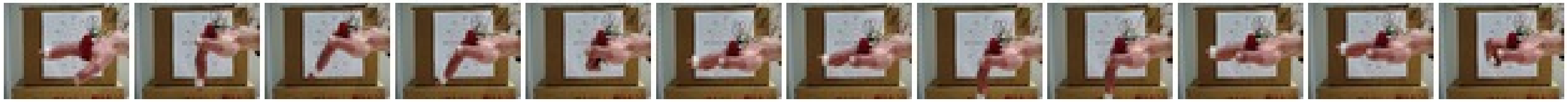
- Estimation takes 0.837s per measurement set

  → No real time behaviour

Results

Estimating one finger – best set

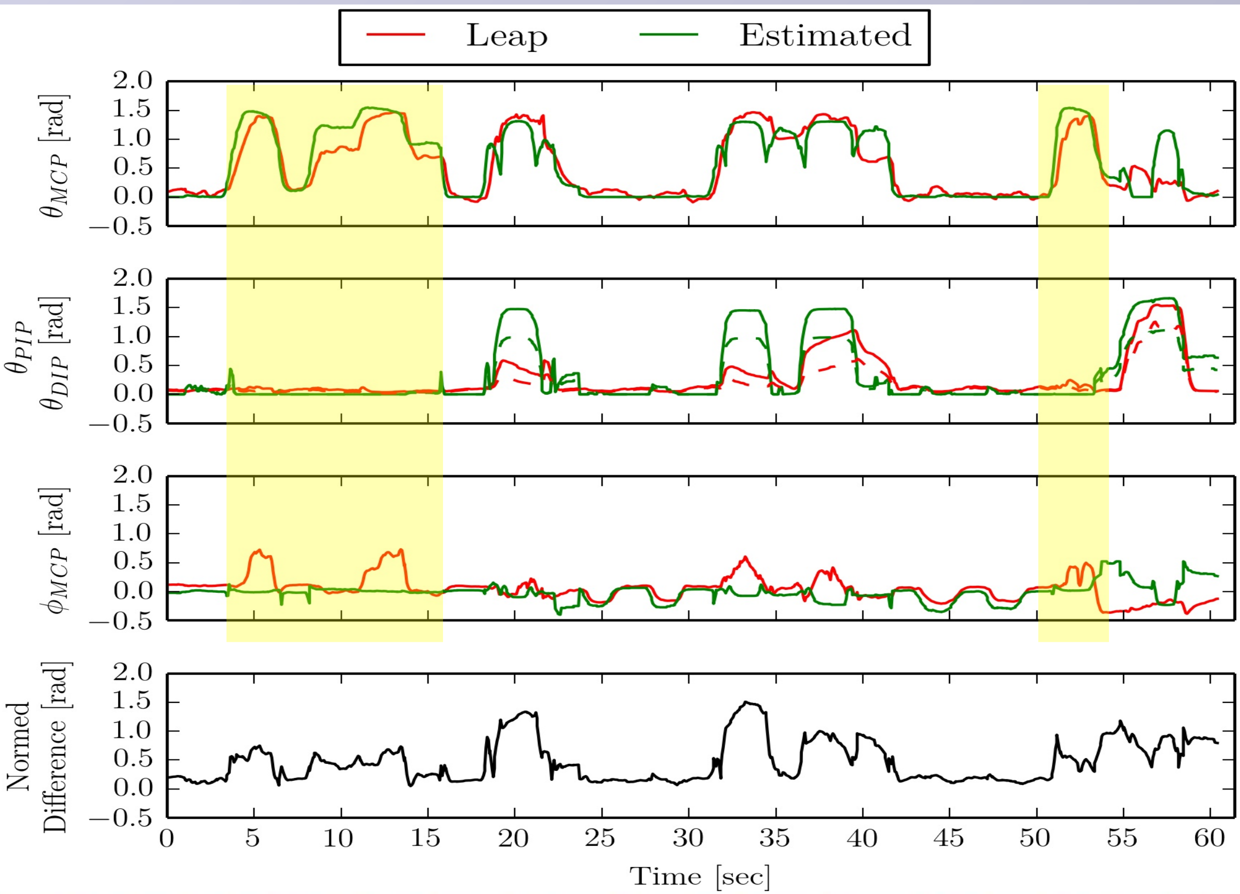




00s 05s 10s 15s 20s 25s 30s 35s 40s 45s 50s 55s

Results

Estimating one finger – best set

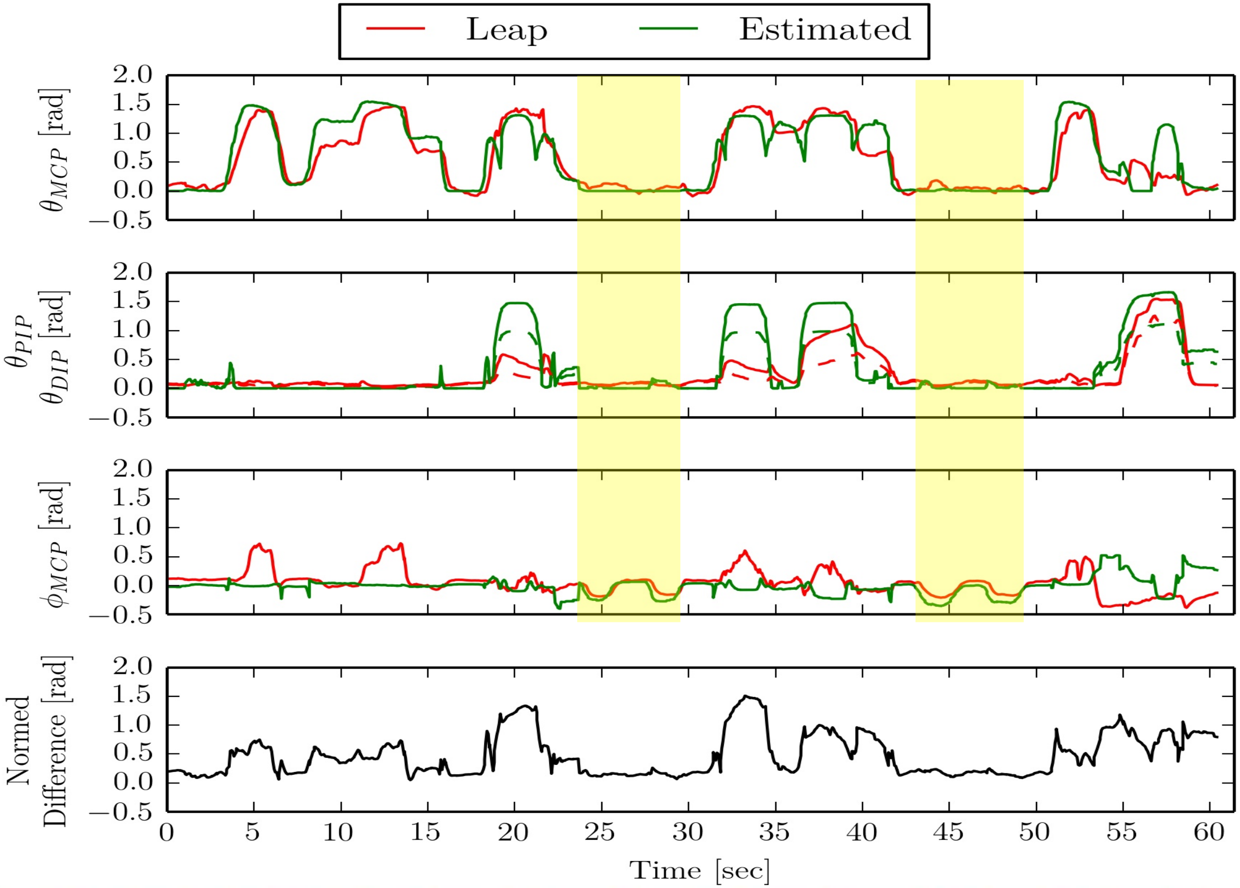


- Flexion-extension of MCP joint:

  → $\mu_{\theta_{\mathrm{MCP}}} = -7.448^\circ \pm 0.172$

Results

Estimating one finger – best set

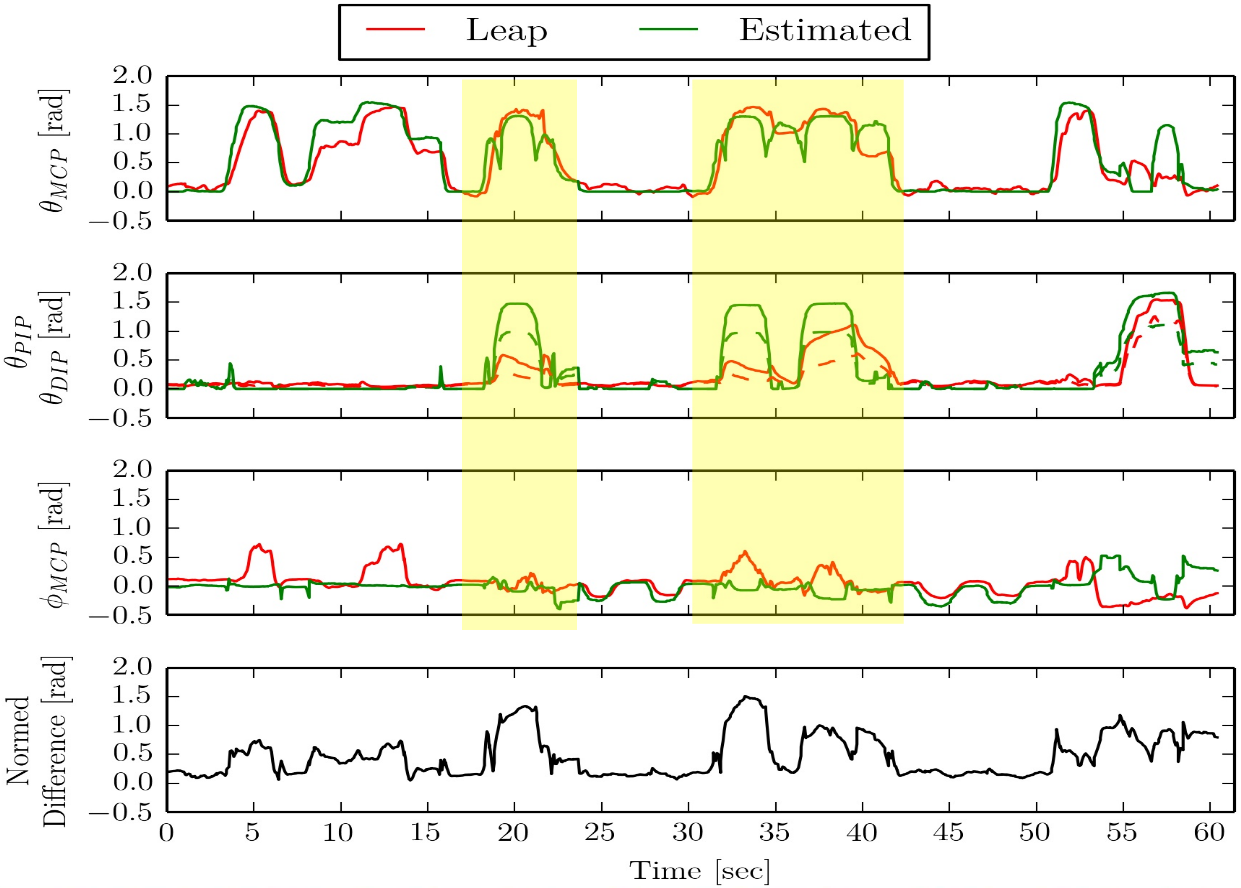


- Adduction-abduction of MCP joint:

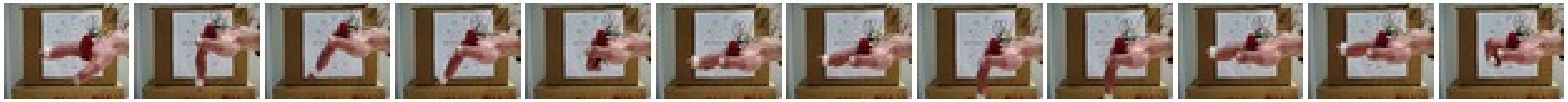
  → $\mu_{\phi_{\mathrm{MCP}}} = 4.698° \pm 0.0$

Results

Estimating one finger – best set



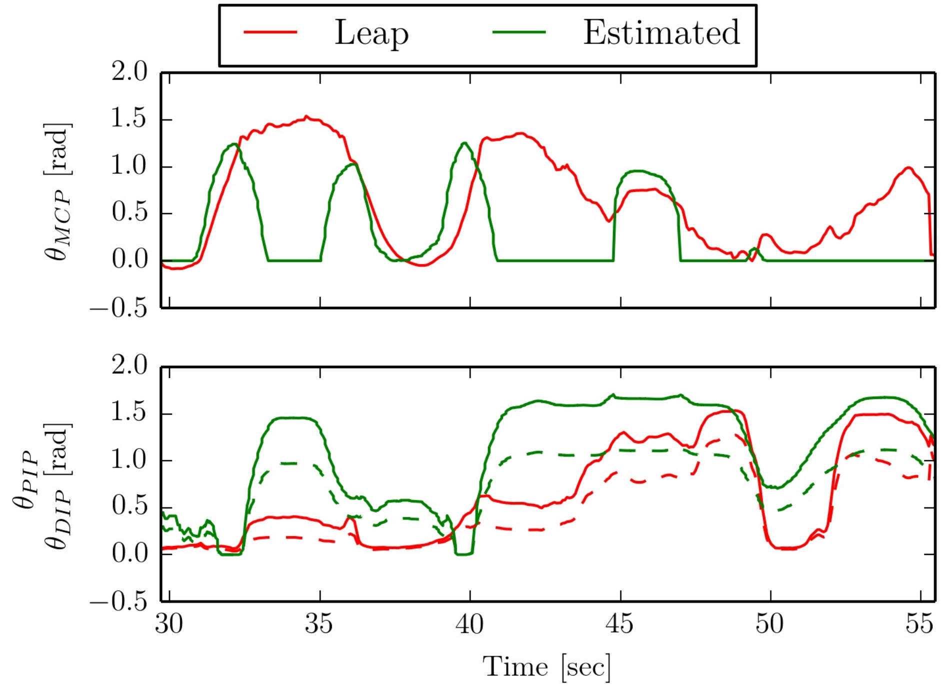
- Bending to fist:
  - → $\mu_{\theta_{\mathrm{MCP}}} = 2.005^\circ \pm 0.229$
  - → $\mu_{\theta_{\mathrm{PIP}}} = -13.866^\circ \pm 3.552$

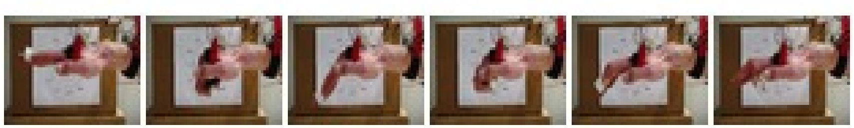


00s 05s 10s 15s 20s 25s 30s 35s 40s 45s 50s 55s

Results

Estimating one finger – bending to fist





30s 35s 40s 45s 50s 55s

- $\mu_{\theta_{\mathrm{MCP}}} = 21.486° \pm 6.188$
- $\mu_{\theta_{\mathrm{PIP}}} = -26.413° \pm 1.146$

- “0-cases” for θ_{MCP} values occur because no solution is found by the minimizer
- This is introduced by:
  - Bad accuracy of hand dimensions
  - Fitting gesture scales linearly for stretched finger only

Results

Estimating one finger – Observations and Limitations

- Motion trackable for single flexion-extension of θ_{MCP} and lateral movement of MCP joint $(= \phi_{\mathrm{MCP}})$
- Results while bending to fist lead to bad values for θ_{MCP}
- Critical influence factors:
  - Accuracy of hand dimensions
    → Can not totally be compensated by fitting gesture
  - Constant position of hand
  - System frequency → Motion speed
- Objective function formulation:
  - System has to be overdetermined $N > K$

Demo

Conclusion and Future Work

- Reconstruction of a single finger is possible, dependent on several influence factors:
  - Error prone determination of hand dimensions

    → Find a more exact measuring method
  - Influence of earth magnetic field

    → Find a method to cancel the surrounding field dynamically
  - Data acquisition rate of sensor system

    → Employ faster sensors and microcontroller

  → Lowest mean difference to Leap Motion over all 4 joint angles for a whole set: $27.330° \pm 0.974$

- Basic HCI could be one field of application for the presented system
  - Navigating cursor in two directions
  - Detecting gestures

Bibliography

[1] Northern Digital: *Optrak Certus Brochure*

[2] Vicon Motion Systems LTD: *Vicon Vantage Brochure*

[3] Synertial Labs: *Synertial, Glove Systems overview*

[4] Zecca, Massimiliano et al.: *On the development of the bioinstrumentation system WB-1R for the evaluation of human-robot interaction.* In: *Advanced intelligent mechatronics, 2007 IEEE/ASME*

[5] Huang, Jiawei et al.: *IM3D: magnetic motion tracking system for dexterous 3D interactions*. In: *ACM SIGGRAPH 2014 Emerging Technologies ACM*

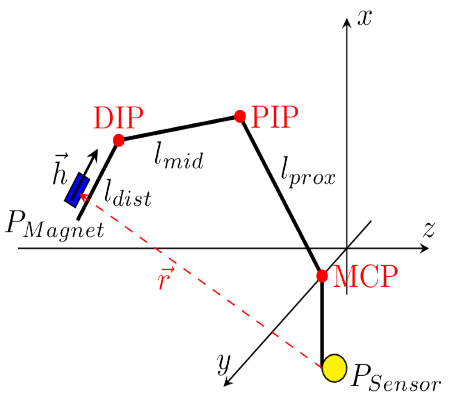
[6] Ma, Yanru et al.: *Magnetic hand motion tracking system for human-machine interaction.* In: *Electronics letters 46 (2010)*

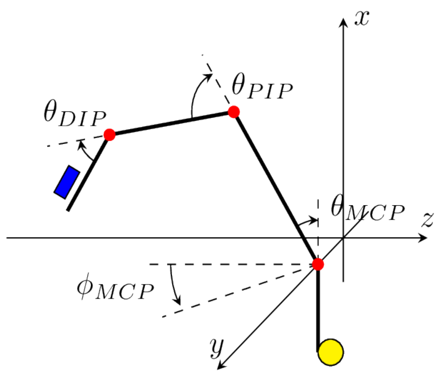
[7] Bullock, Ian M. et al.: *Assesing assumptions in kinematic hand models: a review*. In: *Biomedical Robotics and Biomechatronics (BioRob)*

[8] Lin, John et al.: *Modeling the constraints of human hand motion.* In: *Human Motion, 2000. Proceedings. Workshop on IEEE*

[9] Derby, Norman et al.: *Cylindrical magnets and ideal solenoids.* In: *Amercan Journal of Physics 78 (2010)*

Kinematic Hand Model



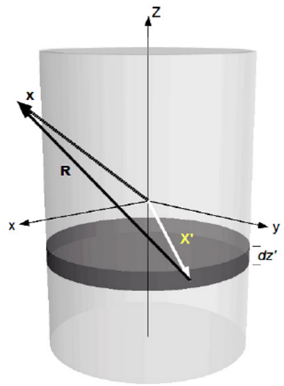


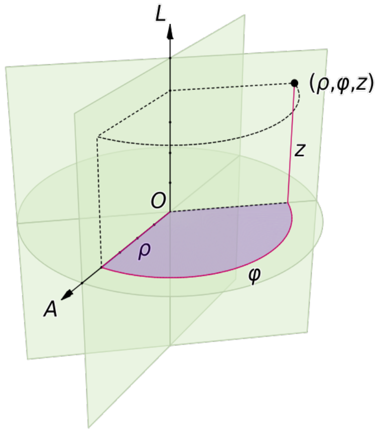
$$h_x = \cos(-\theta_{\mathrm{MCP}} - \theta_{\mathrm{PIP}} - \theta_{\mathrm{DIP}})$$
$$h_y = \cos(-\theta_{\mathrm{MCP}} - \theta_{\mathrm{PIP}} - \theta_{\mathrm{DIP}})\sin(\phi)$$
$$h_z = \sin(-\theta_{\mathrm{MCP}} - \theta_{\mathrm{PIP}} - \theta_{\mathrm{DIP}})\cos(\phi)$$

$$r_x = l_{Prox}\sin(\frac{\pi}{2} - \theta_{\mathrm{MCP}}) + l_{Mid}\sin(\frac{\pi}{2} - (\theta_{\mathrm{MCP}} + \theta_{\mathrm{PIP}})) + l_{Dist}\sin(\frac{\pi}{2} - (\theta_{\mathrm{MCP}} + \theta_{\mathrm{PIP}} + \theta_{\mathrm{DIP}})) + (P_{\mathrm{MCP}_x} - P_{Sensor_x})$$

$$r_y = l_{Prox}\cos(\frac{\pi}{2} - \theta_{\mathrm{MCP}}) + \ldots$$

Cylindircal Magnetic Model





$$C(k_c, p, c, s) = \int_0^{\frac{\pi}{2}} \frac{c \cos^2 \varphi + s \sin^2 \varphi}{(\cos^2 \varphi + p \sin^2 \varphi)\sqrt{\cos^2 \varphi + k_c^2 \sin^2 \varphi}} \, d\varphi$$

Dynamic Cancellation of Earth Magnetic Field

1. Hold the hand with the sensors attached in a stable and calm position
2. The magnets for the fingertips are absent
3. Measure the orientation R_I of the sensors and the corresponding surrounding earth magnetic field B_{earth}
4. After this calibration phase, track the orientation of the hand R_h
5. Calculate the relative orientation $R_d = R_I - R_h$
6. Convert R_d into a rotation matrix rot_d and apply this to B_{earth}
7. Subtract the rotated earth magnetic field from your actual measurement:

$$B = B_{meas} - rot_d \cdot B_{earth}$$