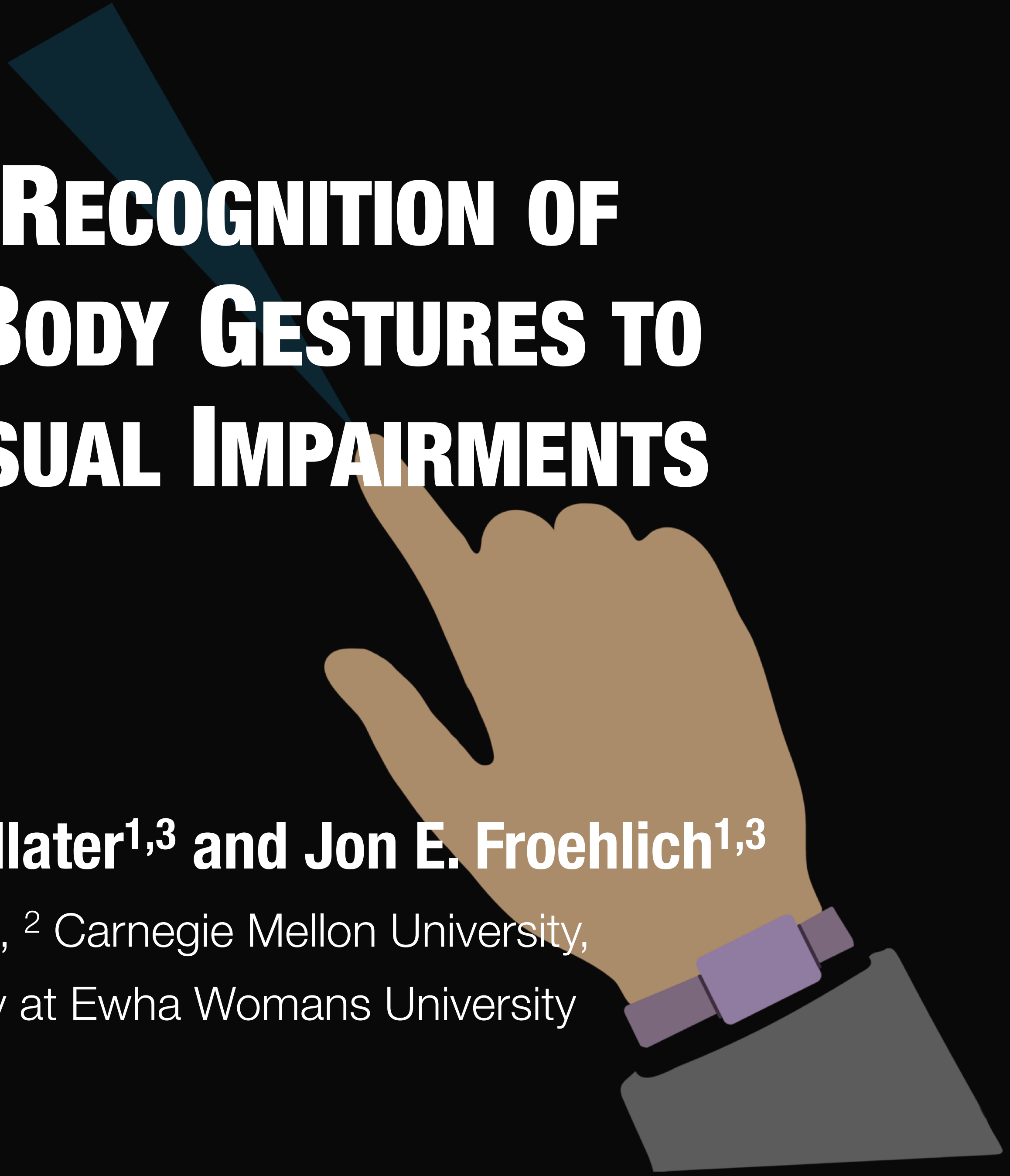
TouchCam: Realtime Recognition of Location-Specific On-Body Gestures to Support Users with Visual Impairments



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On-Body Interaction – Definition

A type of interaction technique which employs the user's own body as an interactive surface

On-Body Interaction – Benefits

(+) Always-available control

On-Body Interaction – Benefits

(+) Always-available control

(+) Expanded input/output space

On-Body Interaction – Benefits

(+) Always-available control

(+) Expanded input/output space

(+) Eyes-free Interaction

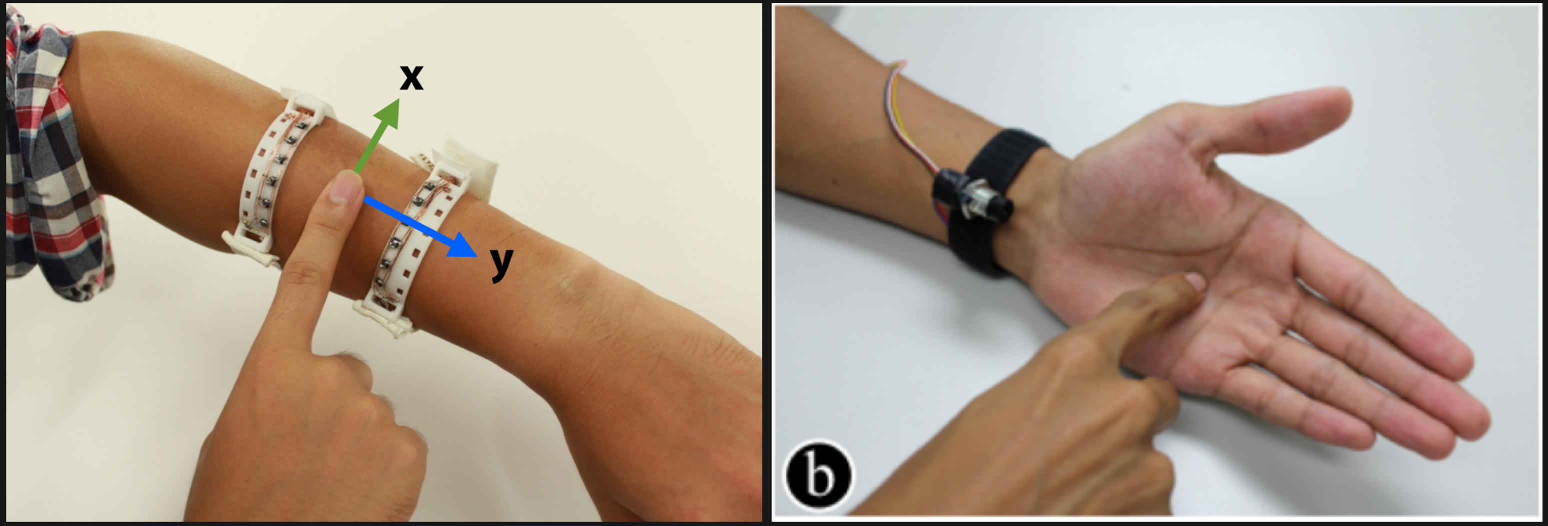
On-Body Input Sensing – Approaches

- Capacitive

Touché [Sato et al. (2012)] (left), iSkin [Weigel et al. (2015)] (right)

ON-BODY INPUT SENSING – APPROACHES

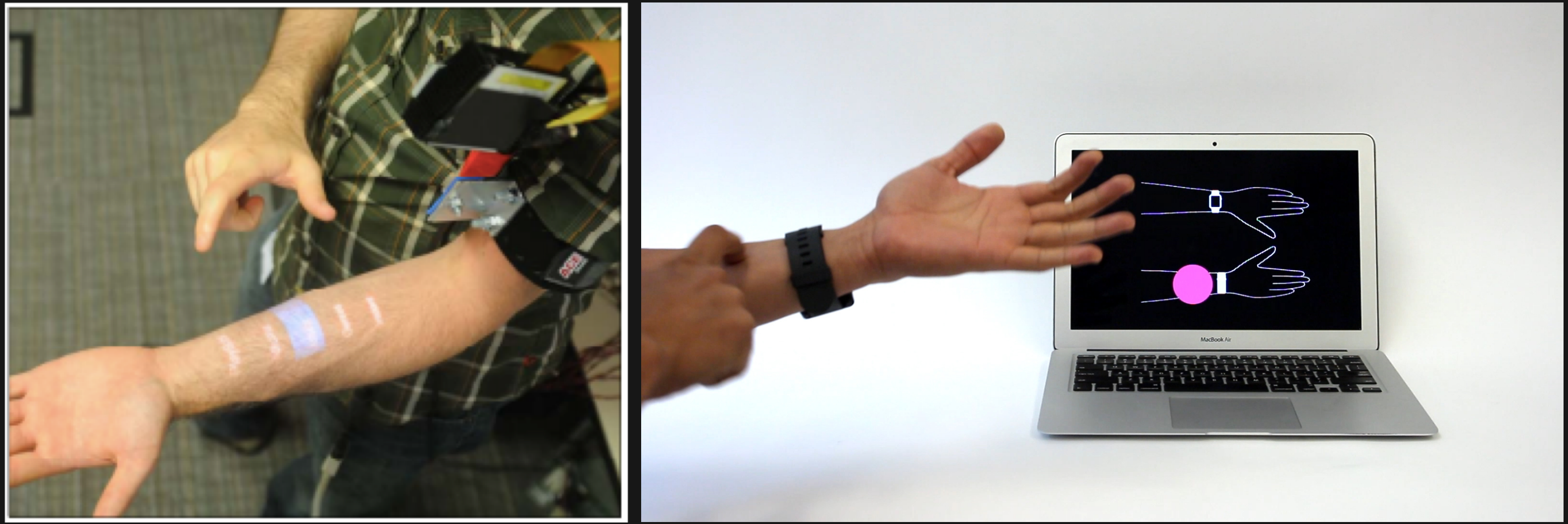
- Capacitive
- Infrared Reflective



SenSkin [Ogata et al. (2013)] (left), PalmGesture [Wang et al. (2015)] (right)

On-Body Input Sensing – Approaches

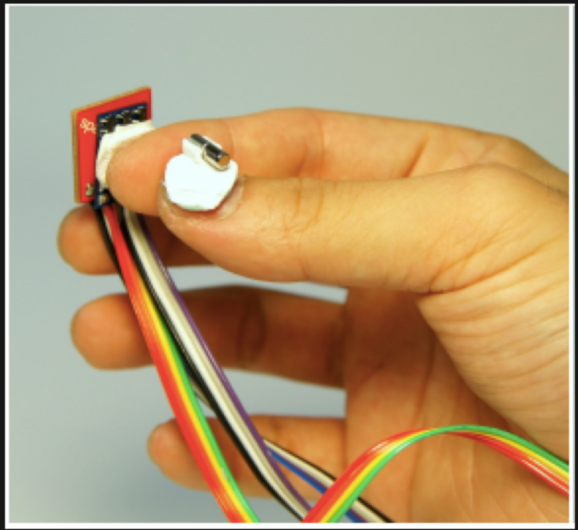
- Capacitive
- Infrared Reflective
- Bio-acoustic



Skinput [Harrison et al. (2010)] (left), ViBand [Gierad et al. (2016)] (right)

ON-BODY INPUT SENSING – APPROACHES

- Capacitive
- Infrared Reflective
- Bio-acoustic
- (Electro) Magnetic



Fingerpad [Chan et al. (2013)] (left), SkinTrack [Zhang et al. (2016)] (right)

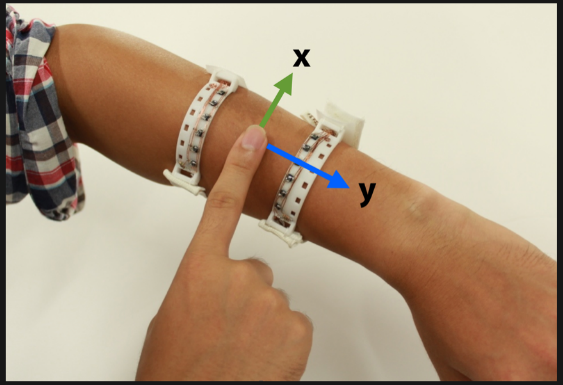
On-Body Input Sensing – Approaches

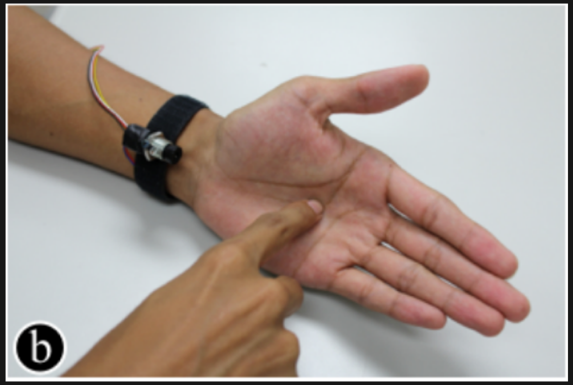
- Capacitive
- Infrared Reflective
- Bio-acoustic
- (Electro) Magnetic
- Optic

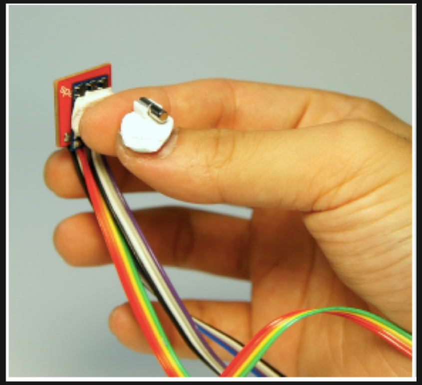
Imaginary Phone [Gustafson et al. (2011)] (left), OmniTouch [Harrison et al. (2011)] (right)

On-Body Input Sensing – Limitations

1. **Interaction space**
    - Small and fixed area
    - Single location

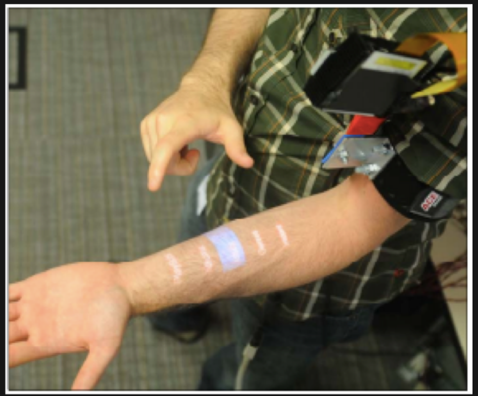






On-Body Input Sensing – Limitations

1. Interaction space
2. Input vocabulary
   - Input localization only
   - Gesture recognition only

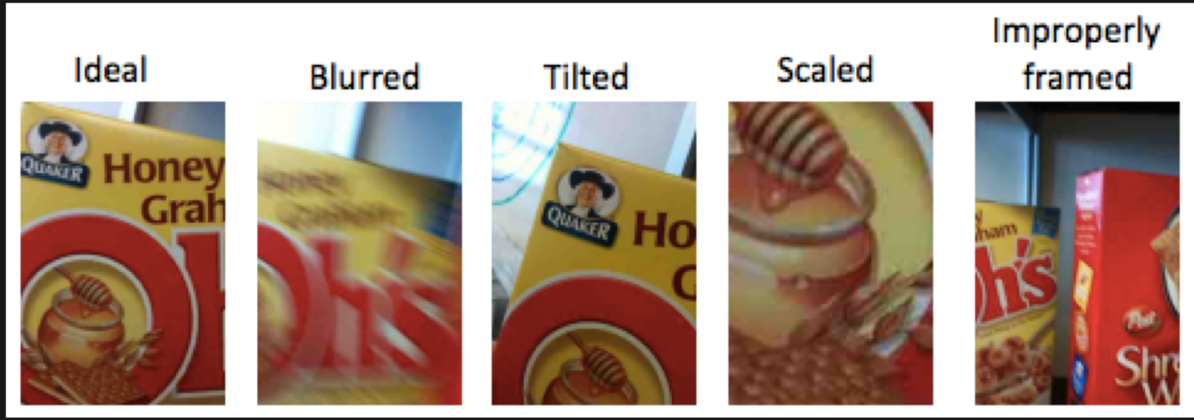


On-Body Input Sensing – Limitations

1. Interaction space
2. Input vocabulary
3. Sensing & touching locations

On-Body Input Sensing – Limitations

1. Interaction space
2. Input vocabulary
3. Sensing & touching locations
   - E.g., Camera for people with visual impairments

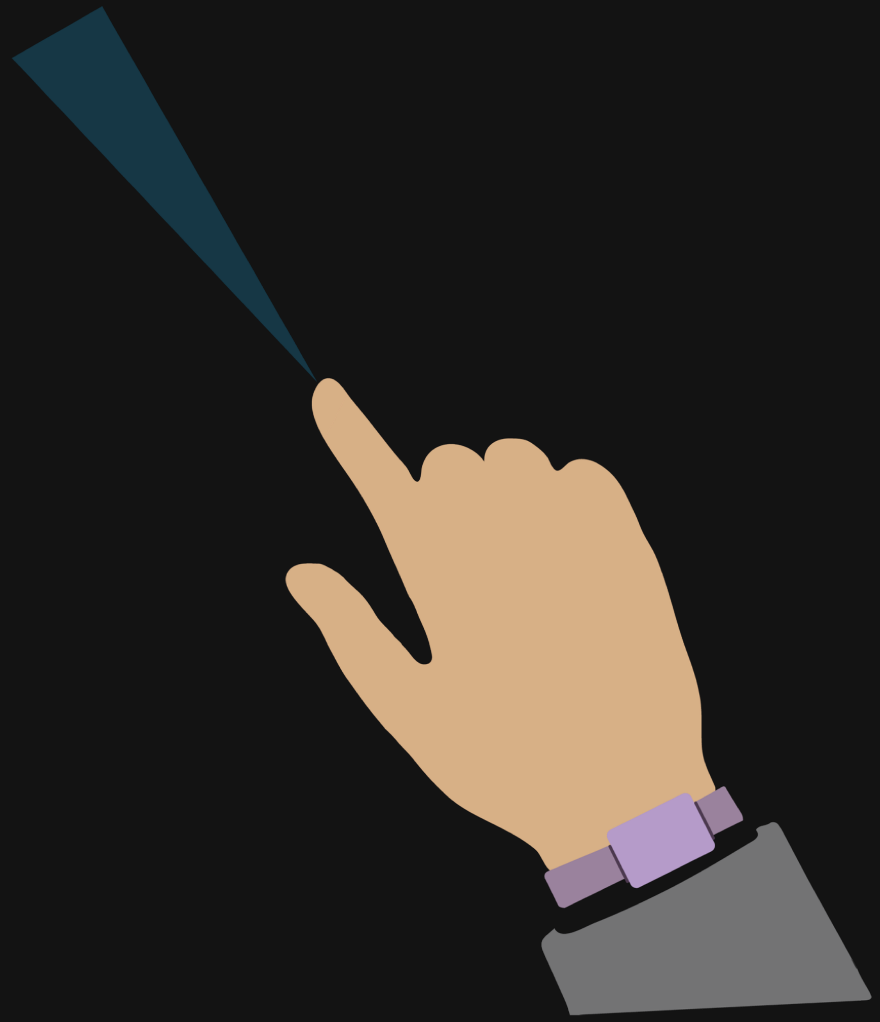


Example pictures taken by people with visual impairments [Bigham et al. (2010)]

On-Body Input Sensing – Limitations

1. Interaction space
2. Input vocabulary
3. Sensing & touching locations
4. Target user
    - Designed and evaluated for typical users only

Our Approach: On-Body Input Recognition Using Finger-Worn Sensors

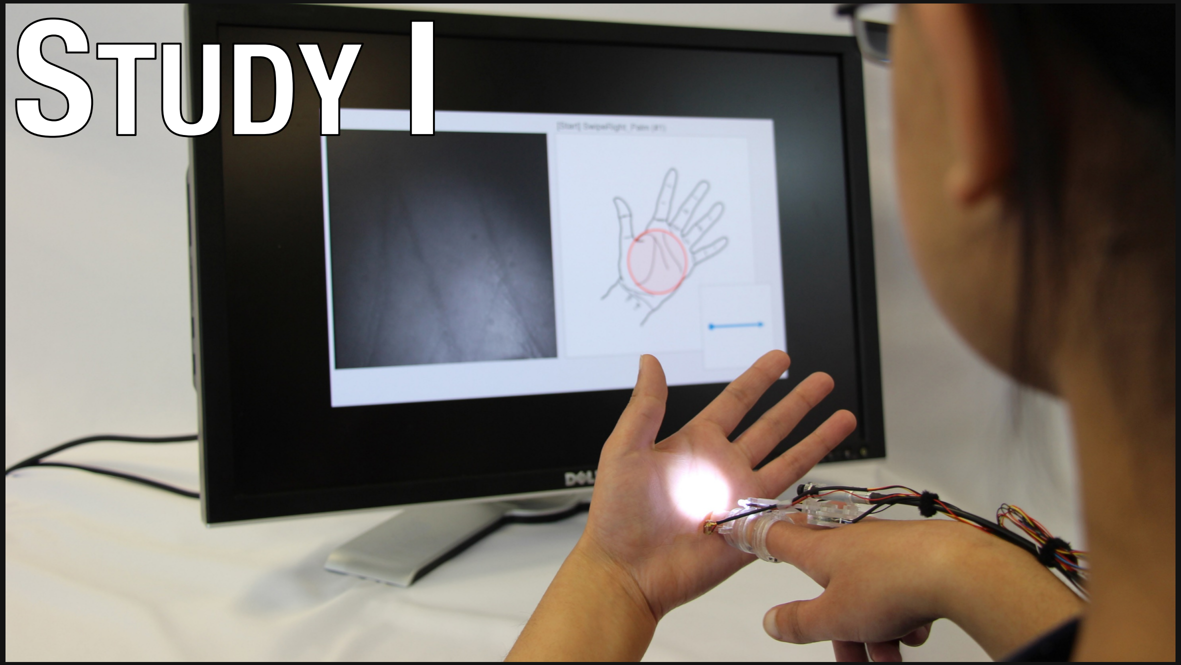


Our Approach: On-Body Input Recognition Using Finger-Worn Sensors

Advantages

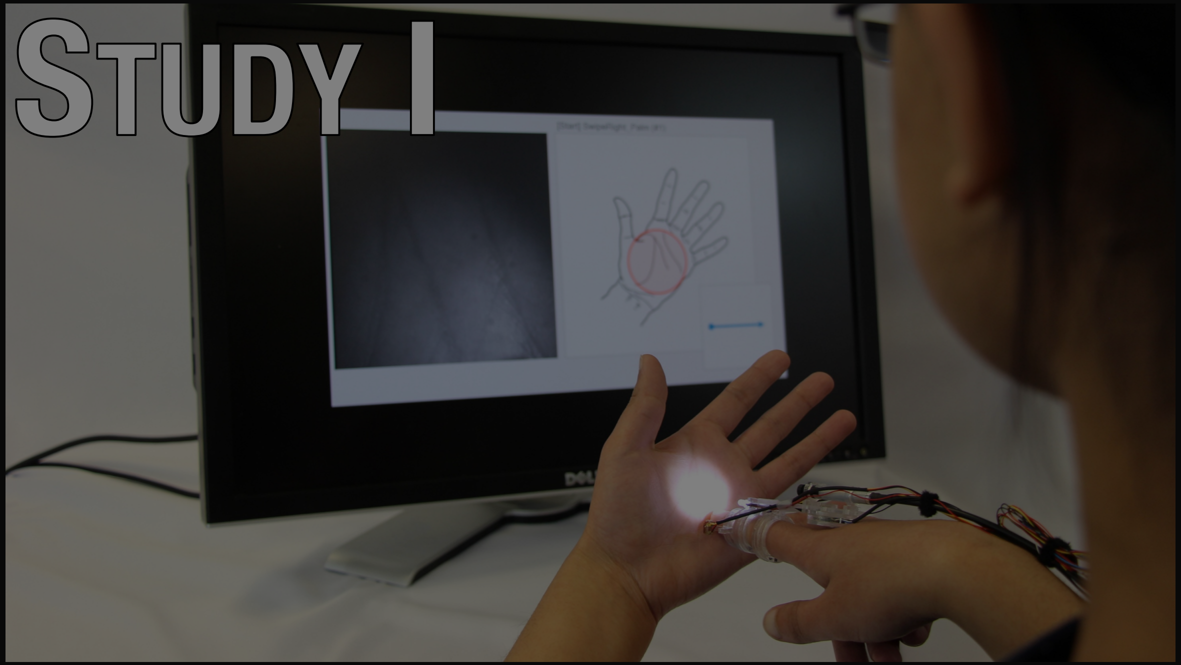
1. Flexible input locations
2. Larger input vocabulary
3. Simplified sensing and processing

TouchCam – Methods



- Goal: to assess the feasibility

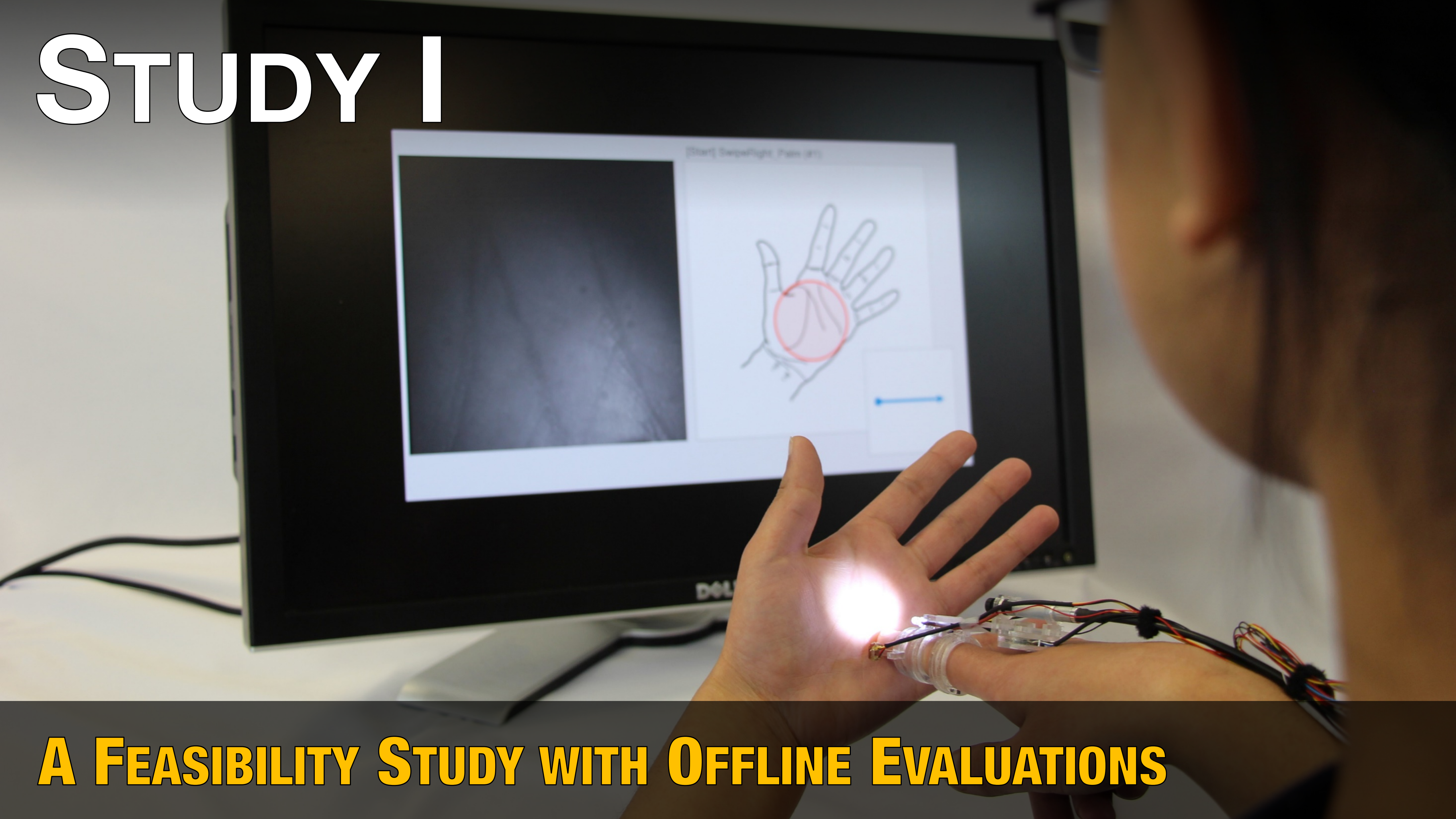
TouchCam – Methods



- Goal: to assess the feasibility

- Goal: to evaluate the usability

Study I

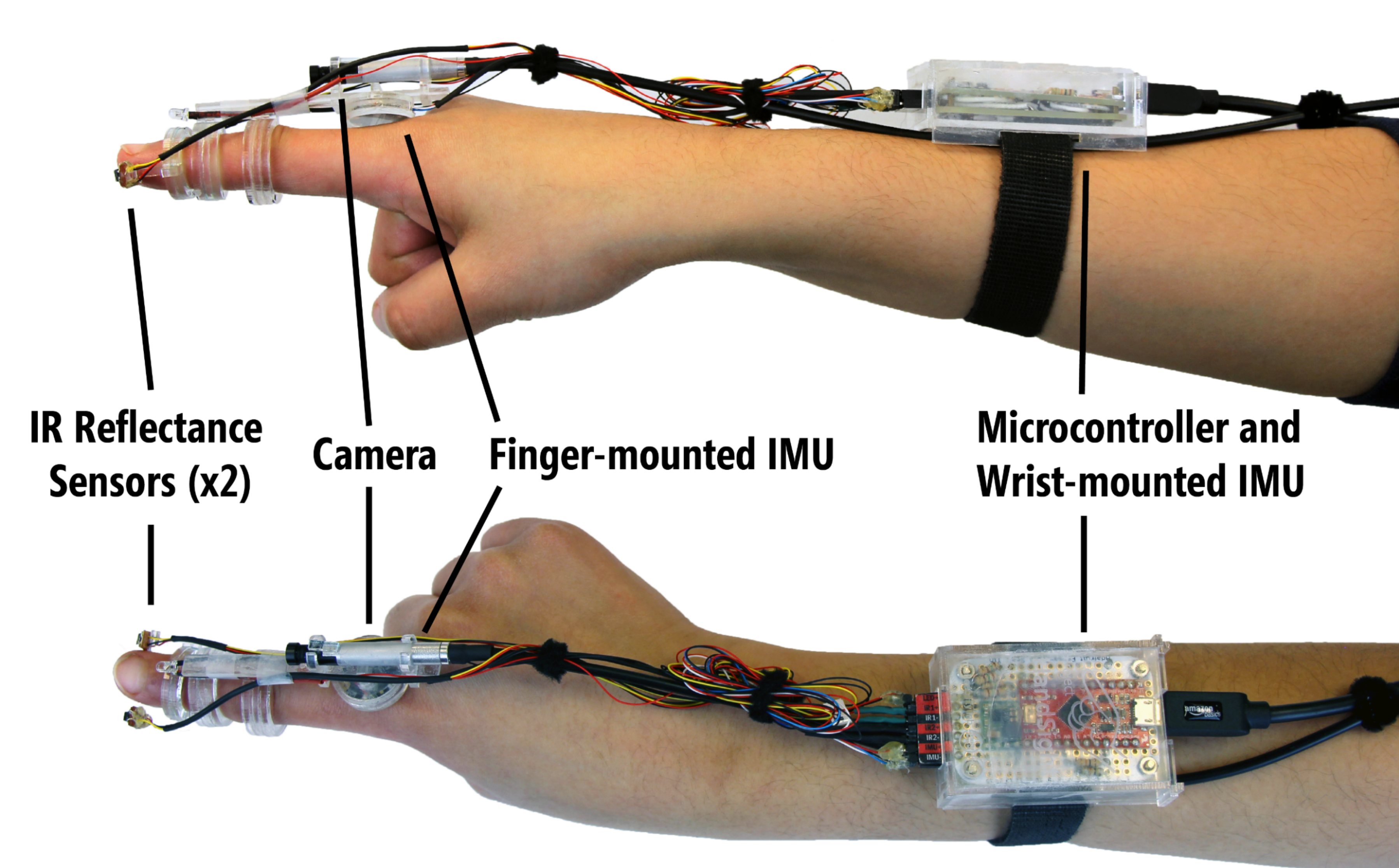


A Feasibility Study with Offline Evaluations

Study I
Participants

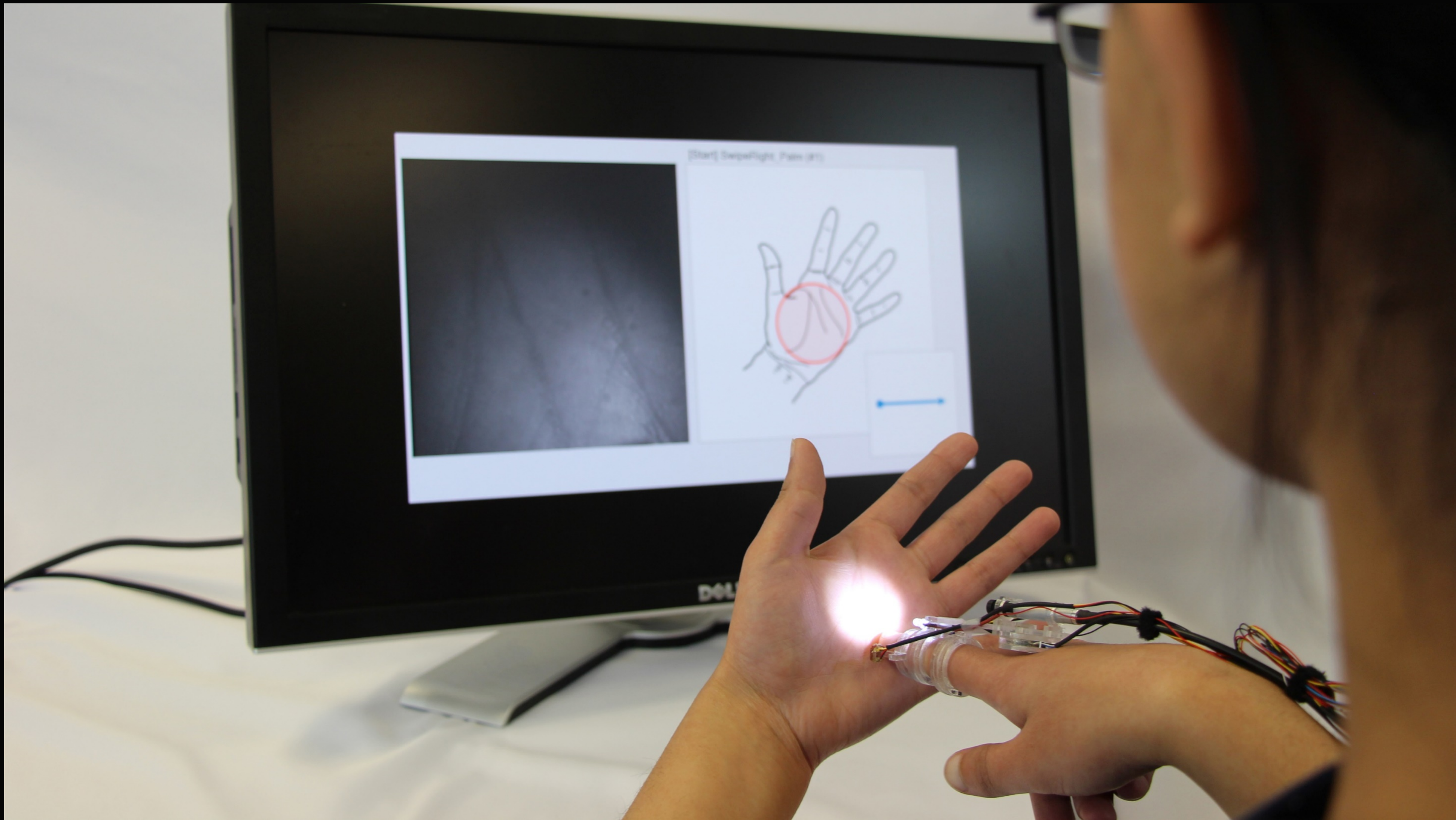
- **The number of subjects:**
  - 24 (16 female, 8 male)
- **Avg. age:**
  - 28.9 (*SD* = 7.95, range: 19 - 51)
- **Level of vision:**
  - Normal or corrected-to-normal

Study I
Apparatus – HW Prototype V1



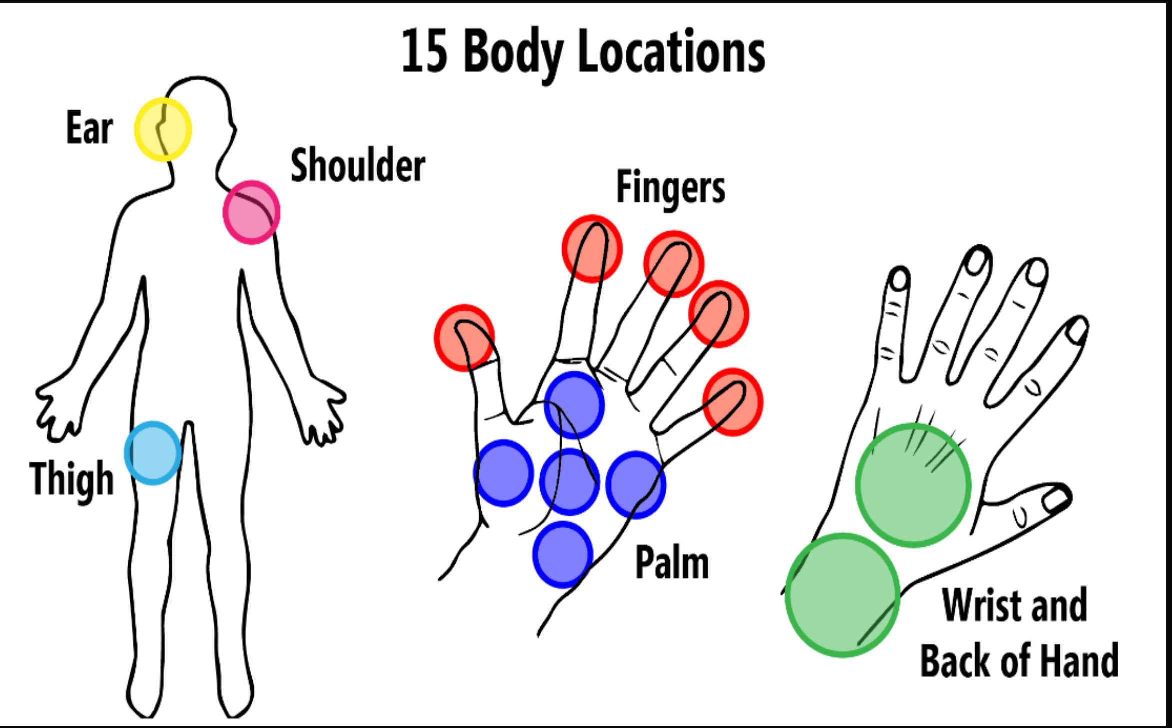
Study I

Apparatus – Data Collection Tool



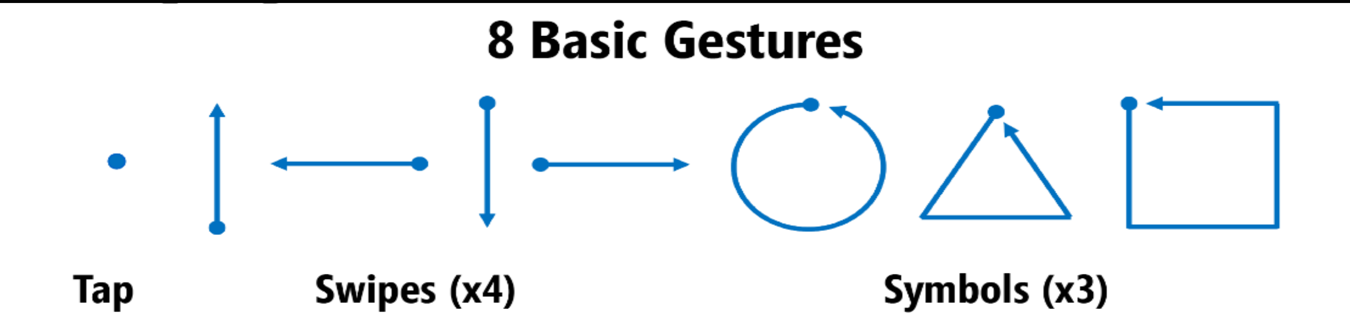
Study I
Procedure (~90 min.)

- **Demographic Questionnaire**
- **System Calibration**
- **Data Collection**
  1. Location-specific touches
     - 15 locations x 10 blocks



STUDY I
PROCEDURE (~90 MIN.)

- **Demographic Questionnaire**
- **System Calibration**
- **Data Collection**
  1. Location-specific touches
  2. Location-specific gestures
     - 3 locations (palm, wrist, thigh) x 8 gestures x 10 blocks



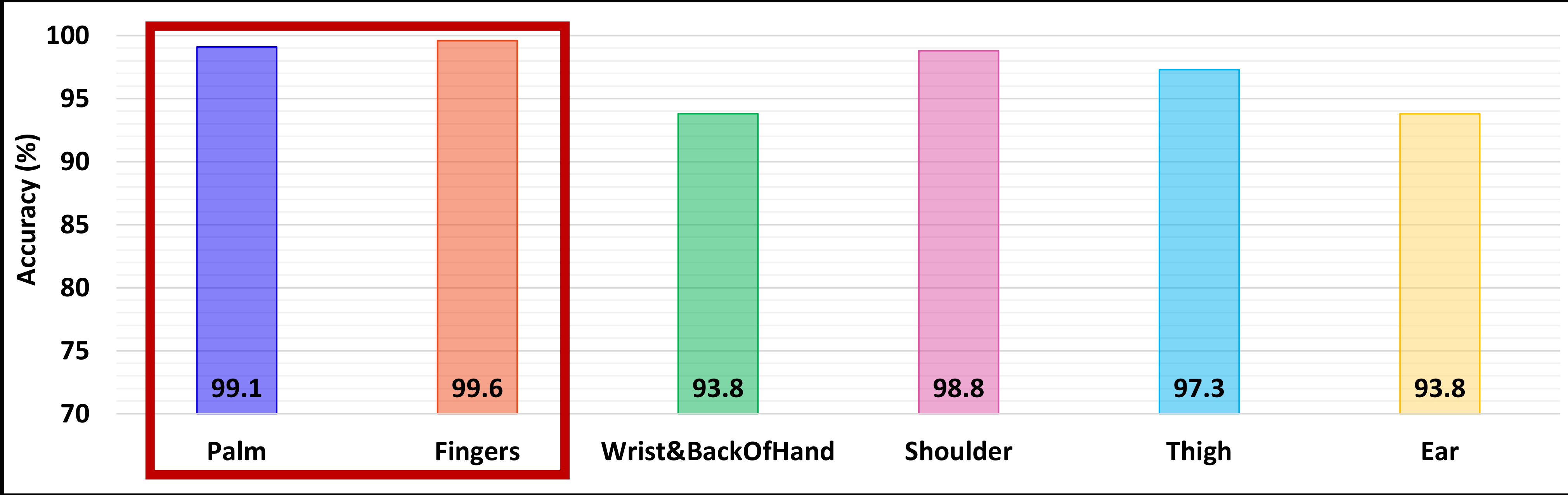
STUDY I
DATA AND ANALYSIS

- **Data Ex:**

Study I
Results – Localization

Fine-Grained Localization Avg. Accuracy: 88.7% (*SD*=7.0%)
(15 classes: PalmCenter, PalmLeft, …)

Coarse-Grained Localization Avg. Accuracy: 98.0% (*SD*=2.3%)
(6 classes: palm, fingers, wrist and back of hand, shoulder, thigh, ear)



Study I

Results – Sensor Combinations

Fine-Grained Accuracy:

- 88.7% with all sensors
- 84.0% with camera only
- 52.9% with all sensors except camera

Coarse-Grained Accuracy:

- 98.0% with all sensors
- 97.5% with camera only
- 87.5% with all sensors except camera

*Coarse-Grained: $p<.001$, $t(23) = 7.12$, $d=1.92$; Fine-Grained: $p<.001$ $t(23) = 16.74$, $d=2.99$

STUDY I
RESULTS – GESTURE RECOGNITION

Location-Specific Gestures Avg. Accuracy: 95.7% (*SD*=3.2%)

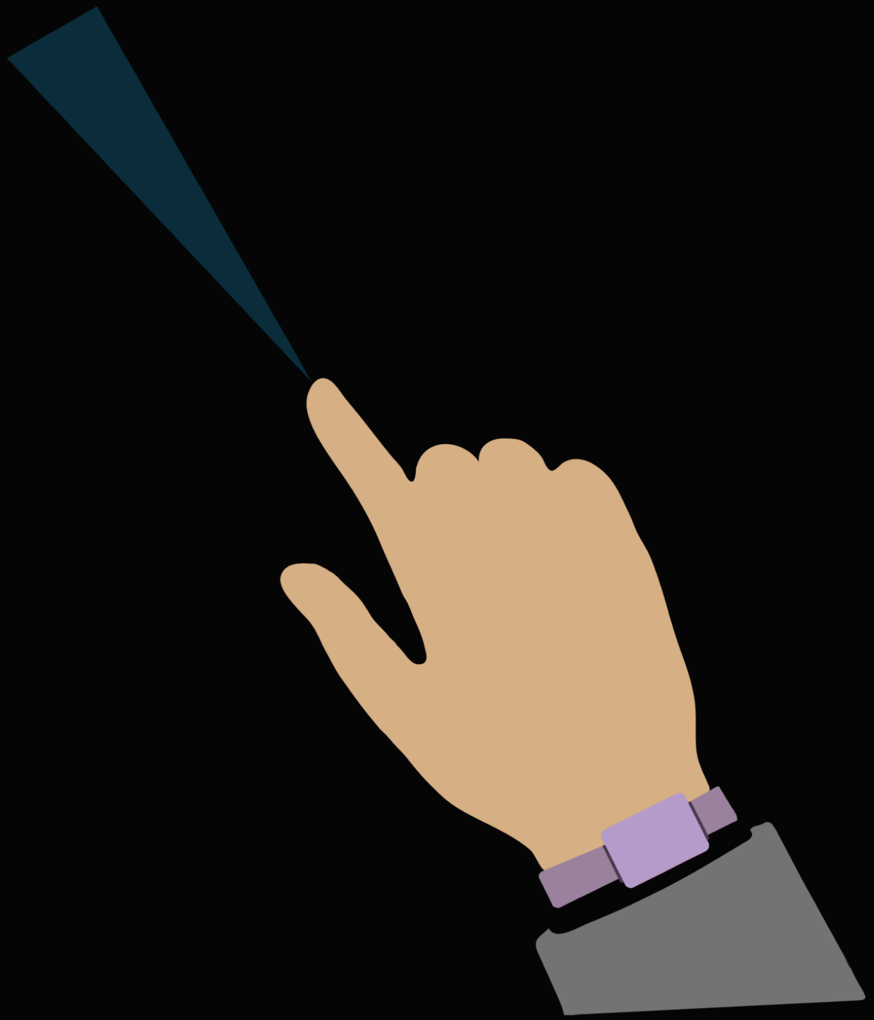
(24 classes: palm-swipeUp, wrist-swipeUp, …, palm-swipeDown, …)

Accuracy for different sensor combinations:

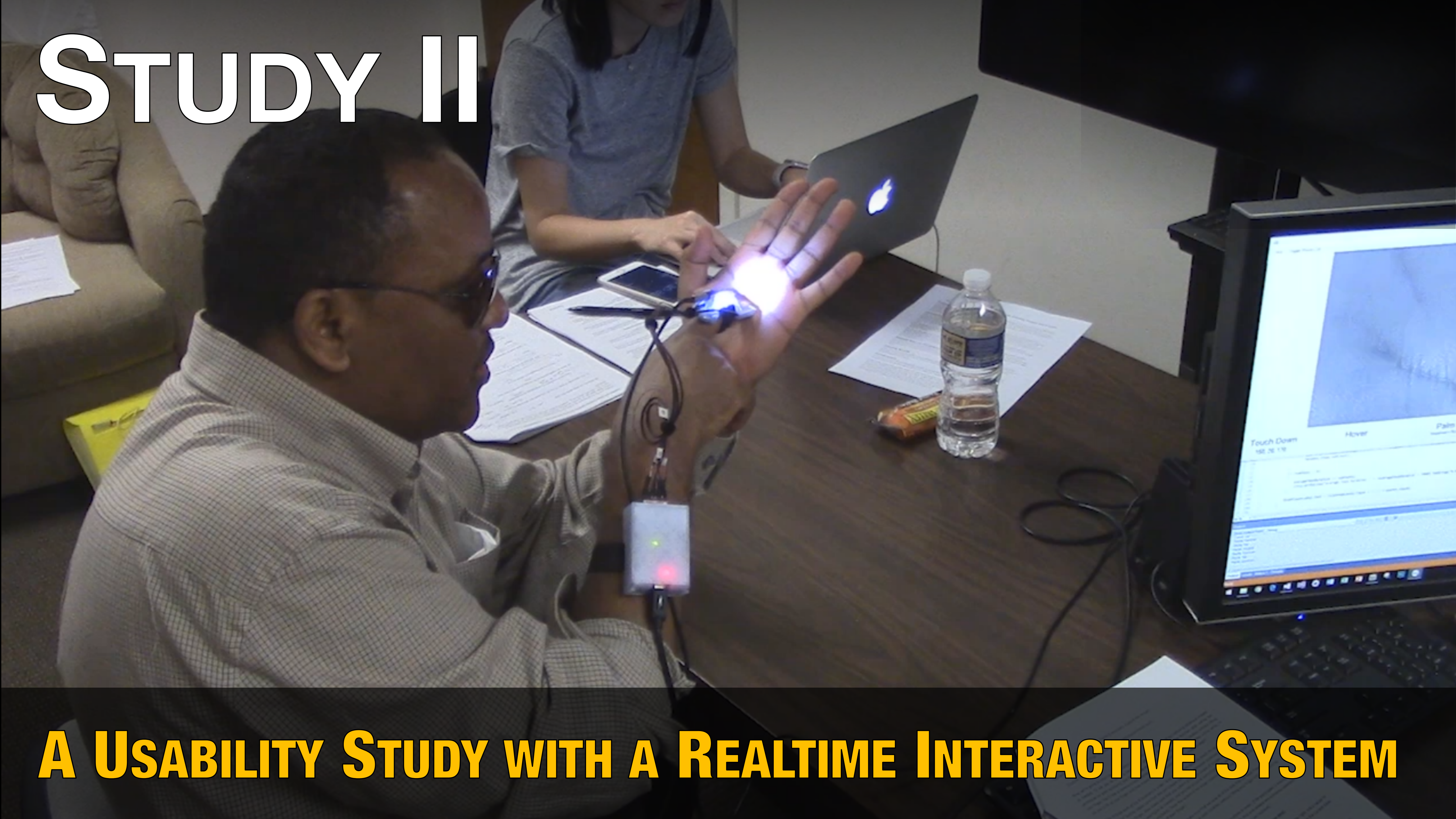
- 84.6% with camera only
- 91% and 91.4% with one IMU (finger vs. wrist)
- 95.1% with two IMU’s
- 95.4% with camera and two IMU’s

Study I
Summary

- **The feasibility evaluation:**
  - Accuracy
    - 88%–98%
  - Efficiency
    - Too slow (approx. 2 sec. per image)
- **Advantages with sensor fusion:**
  - Sensor combination can be optimized



Study II

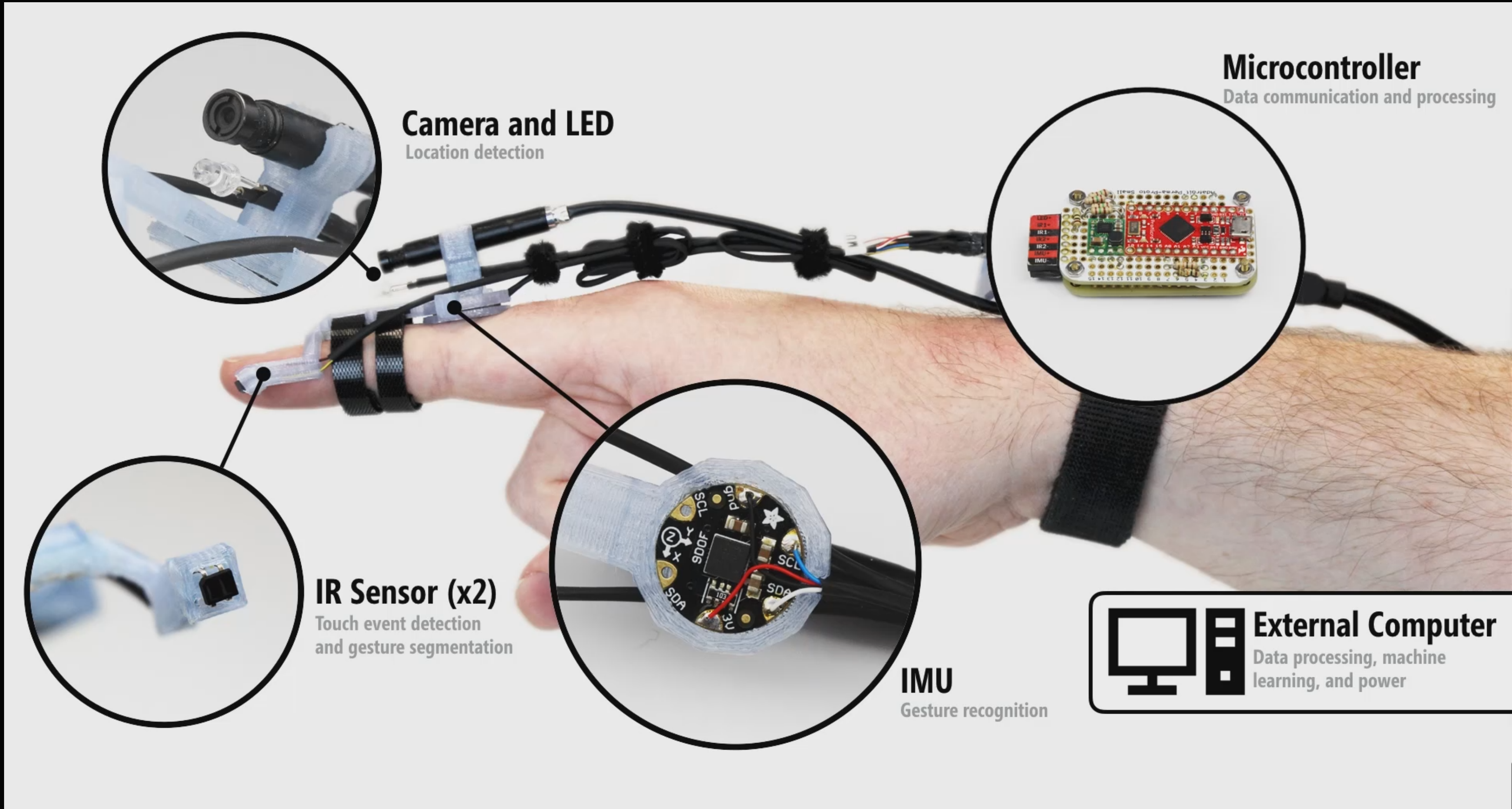


A Usability Study with a Realtime Interactive System

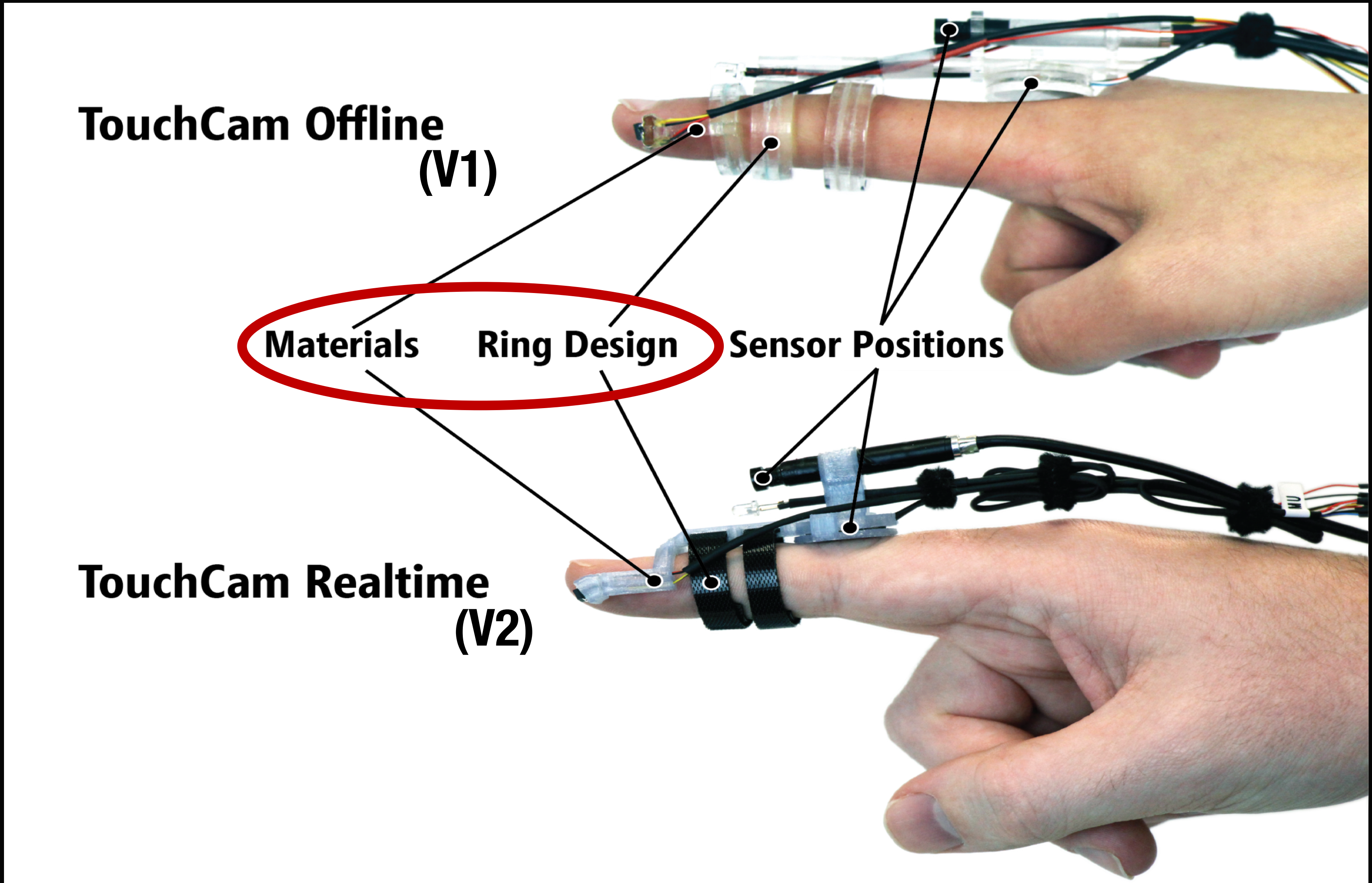
Study II
Participants

- **The number of subjects:**
  - 12 (7 female, 5 male)
- **Avg. age:**
  - 46.2 (*SD* = 12.0, range: 29 - 65)
- **Level of vision:**
  - 9 blind, 3 low vision

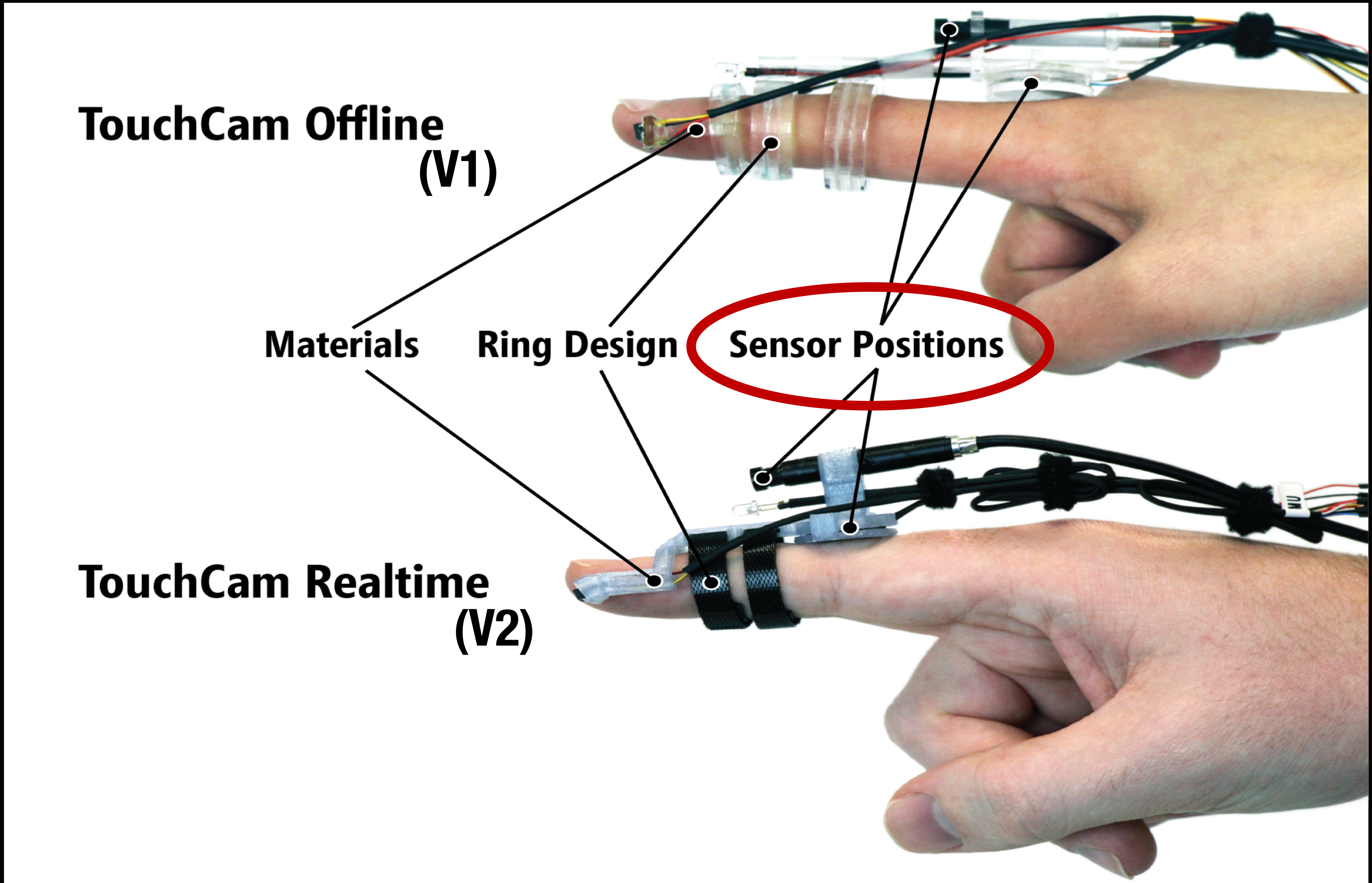
Study II
Apparatus – HW Prototype V2



Study II
Apparatus – HW Prototypes



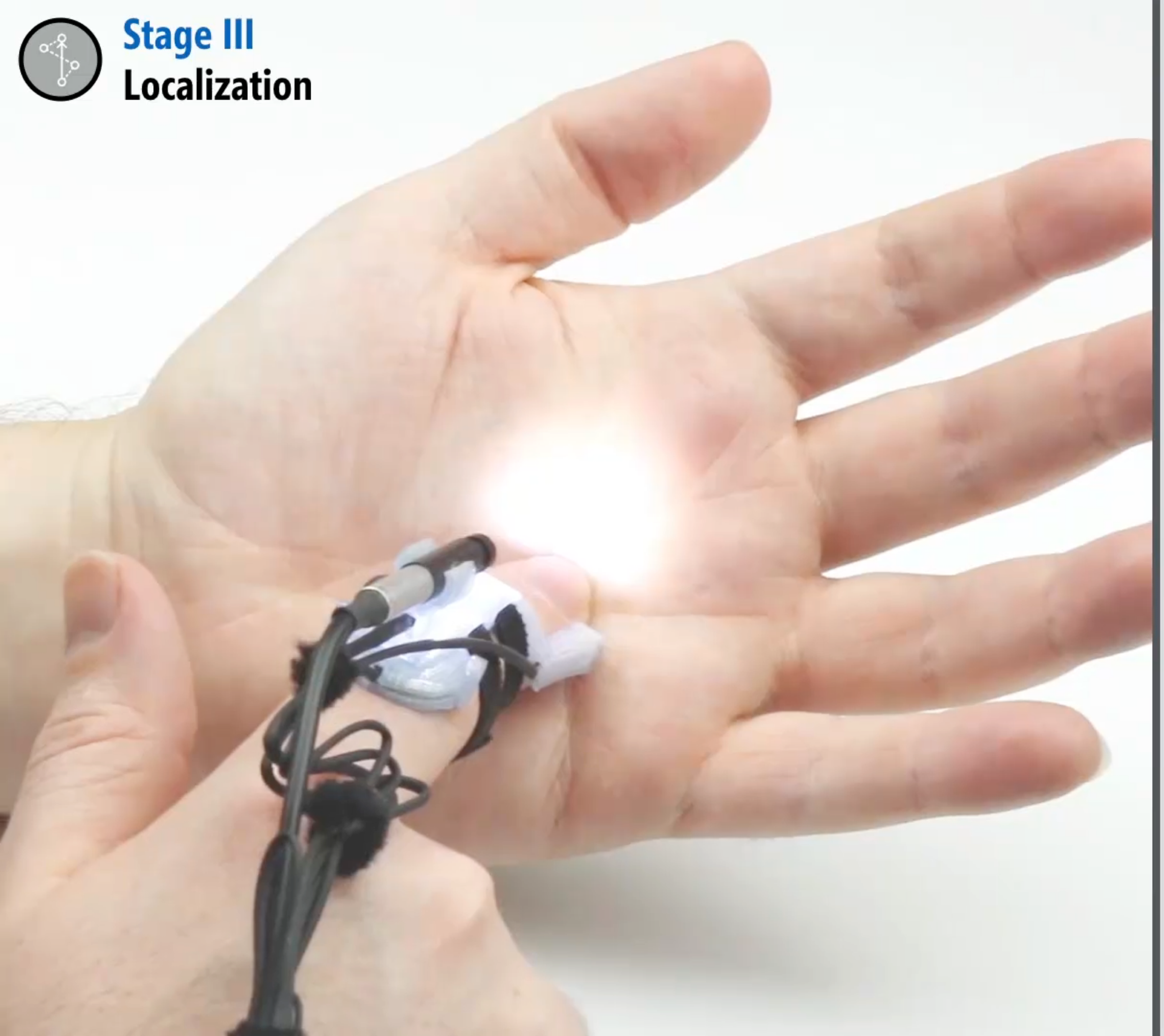
Study II
Apparatus – HW Prototypes



Study II
Data and Analysis – Recognition

Stage I: Touch Segmentation
Stage II: Feature Extraction
Stage III: Localization
Stage IV: Gesture Classification

Stage III
Localization



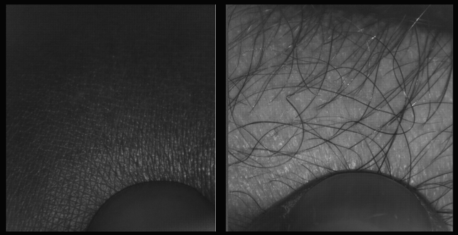
Signals

Camera

STUDY II
PROCEDURE (~120 MIN.)

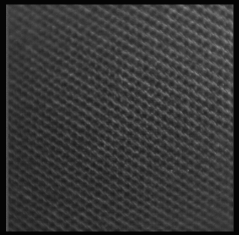
- **Interview**
- **System calibration and training**
- **Tasks**
  1. Location-specific touches
     - 9 locations

Palm: up, down, left, right, center



Wrist: inner, outer

Ear



Thigh

Study II

Procedure (~120 min.)

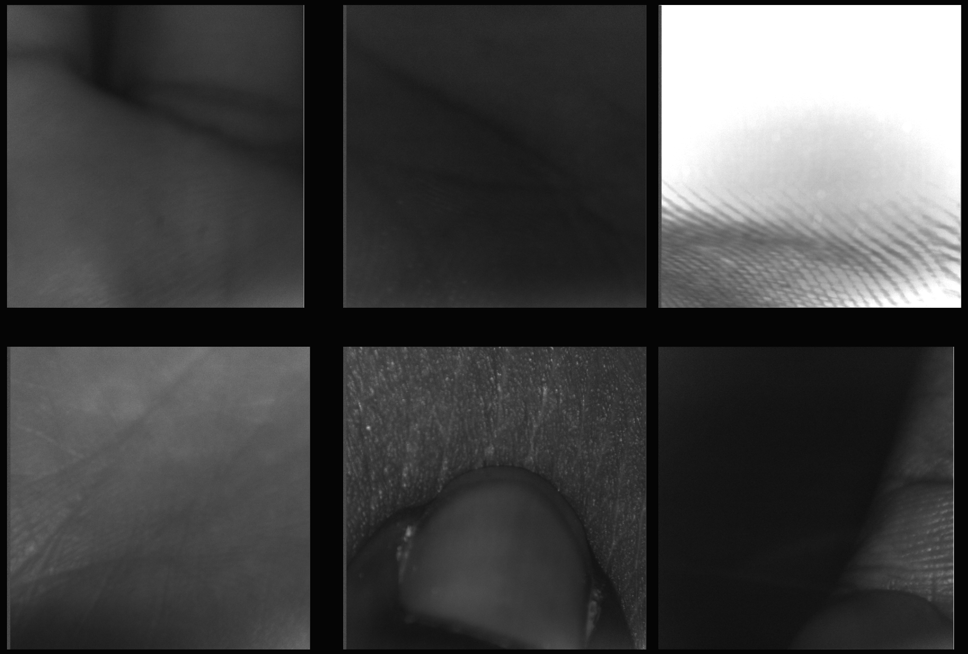
- **Interview**
- **System calibration and training**
- **Tasks**
  1. Location-specific touches
  2. Basic mobile tasks with 3 interaction designs

STUDY II
PROCEDURE (~120 MIN.)

- Interview
- System calibration and training
- Tasks
- Post-study questionnaires

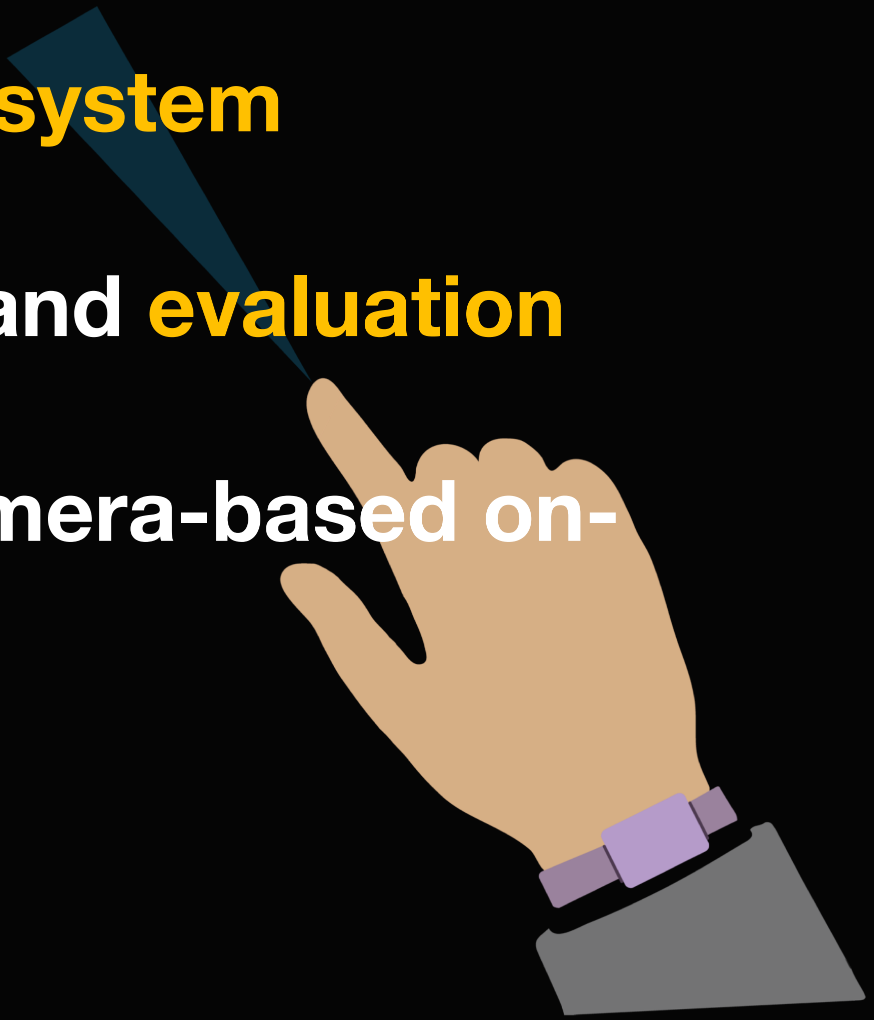
Results – Localization Accuracy

- **Leave-one-out cross-validation** (*N*=12)
  - 81.3% with 9 classes
  - 94.2% with 4 classes (i.e., palm, wrist, ear, thigh)
- **Issues with images** (22%)
  - 13.6% with poor focus
  - 5.4% with insufficient illumination
  - 4.3% with poor contrast
  - 3.2% with target uncaptured



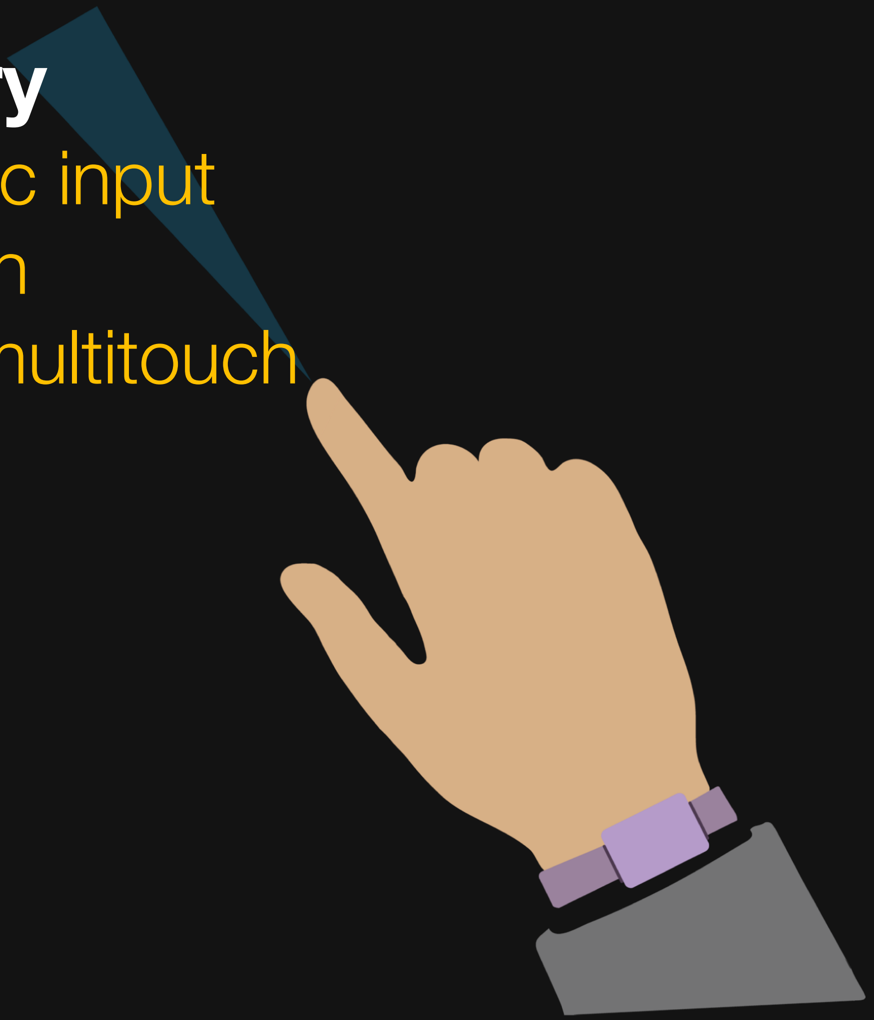
Study II
Summary

- **Developed a realtime interactive system**
  - Iterative design process
- **Assessed realtime performance and evaluation with our target population**
- **Identified obstacles to robust camera-based on-body input recognition**



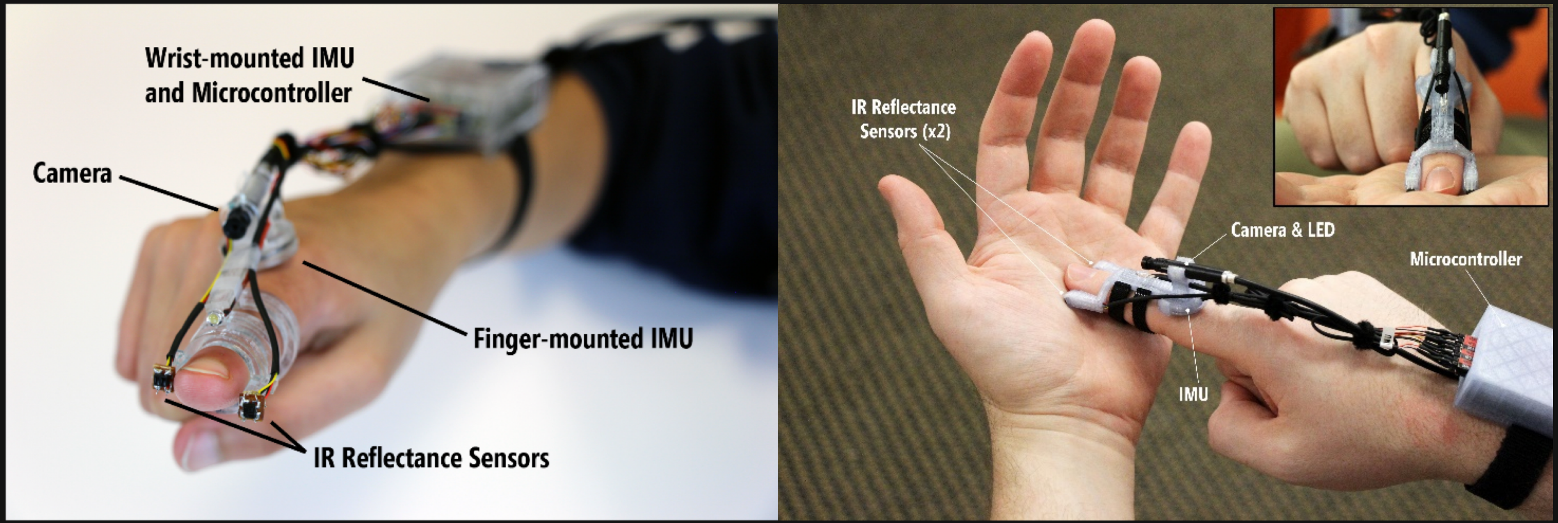
TouchCam – Discussion and Future work

- **The benefits**
  - **Expanded on-body input vocabulary**
    - Location-specific input for context-specific input
    - high degree of flexibility and customization
    - Can be further expanded by supporting multitouch



TouchCam – Discussion and Future work

- The benefits
- The feasibility
    - Physical design
        - Still large, weak computing power
        - Future design should be a small stand-alone device

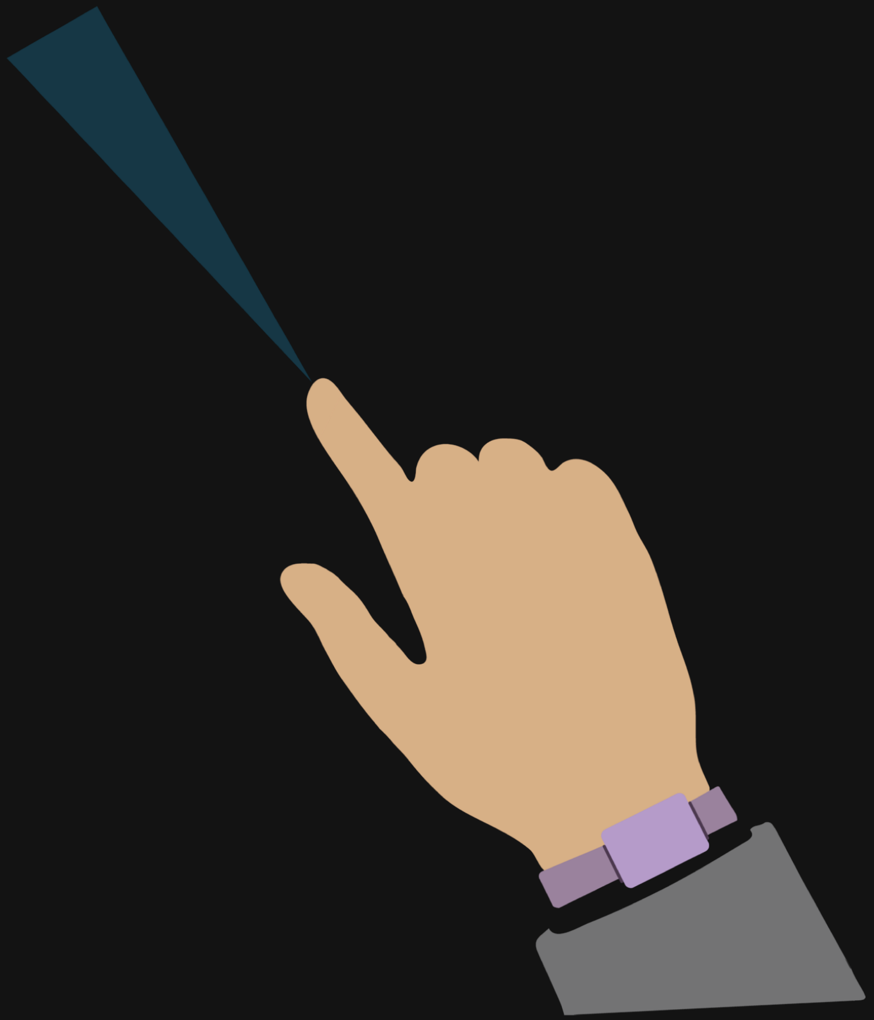


TouchCam – Discussion and Future work

- **The benefits**
- **The feasibility**
  - **Physical design**
  - **Performance**
    - High accuracy with realtime performance
    - Can be improved with
      - Auto-focus
      - Wide-angle camera with higher resolution
      - Efficient finger-,palmprint recognition

TouchCam – Discussion and Future work

- **The benefits**
- **The feasibility**
- **The usability**
  - Training and calibration take time
  - Can be improved with
    - Bootstrapping the system
    - Training as needed



TouchCam – Conclusion

- **Introduced an on-body input sensing system**
  - using sensors worn on the user's gesturing finger
  - for people with visual impairments
- **Demonstrate feasibility with**
  - Accuracy
  - Recognition time
- **Identified design implications and goals for future on-body interfaces**

Thank you ☺

Questions?

You can also reach

Lee Stearns (our first author) at lstearns@umd.edu
or Uran Oh (me) at uran.oh@ewha.ac.kr

TouchCam – References

Localization:

Stearns, L., Oh, U., Cheng, B. J., Findlater, L., Ross, D., Chellappa, R., & Froehlich, J. E. (2016, December). Localization of skin features on the hand and wrist from small image patches. In Pattern Recognition (ICPR), 2016 23rd International Conference on (pp. 1003-1010). IEEE.

Qualitative Analysis:

Oh, U., Stearns, L., Pradhan, A., Froehlich, J. E., & Findlater, L. (2017, October). Investigating Microinteractions for People with Visual Impairments and the Potential Role of On-Body Interaction. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 22-31). ACM.