Introduction to Sensing in HCI

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Contents

- Background
- Visual Sensing
- Acoustic Sensing
- Electrical Sensing
- Electromagnetic Sensing
- Conclusion

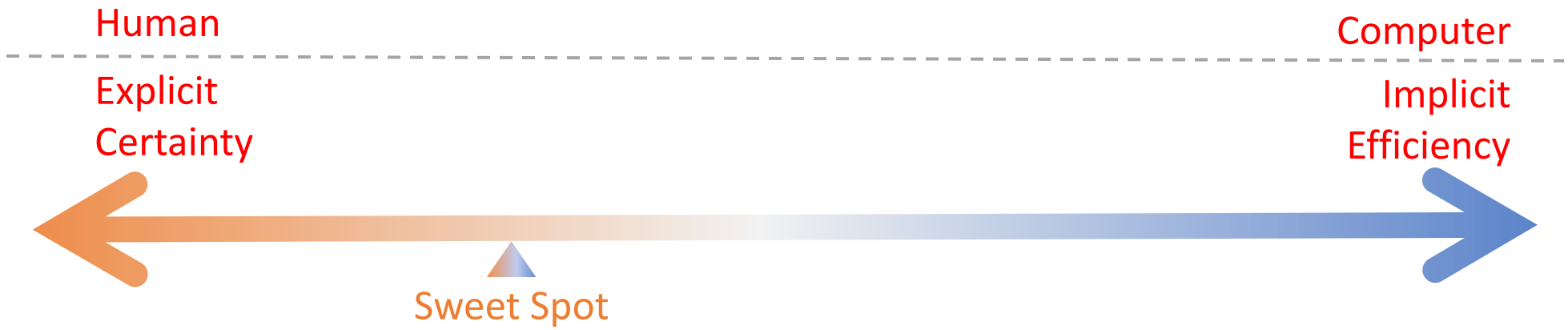
What is a Sensing System?

How human perceives the world

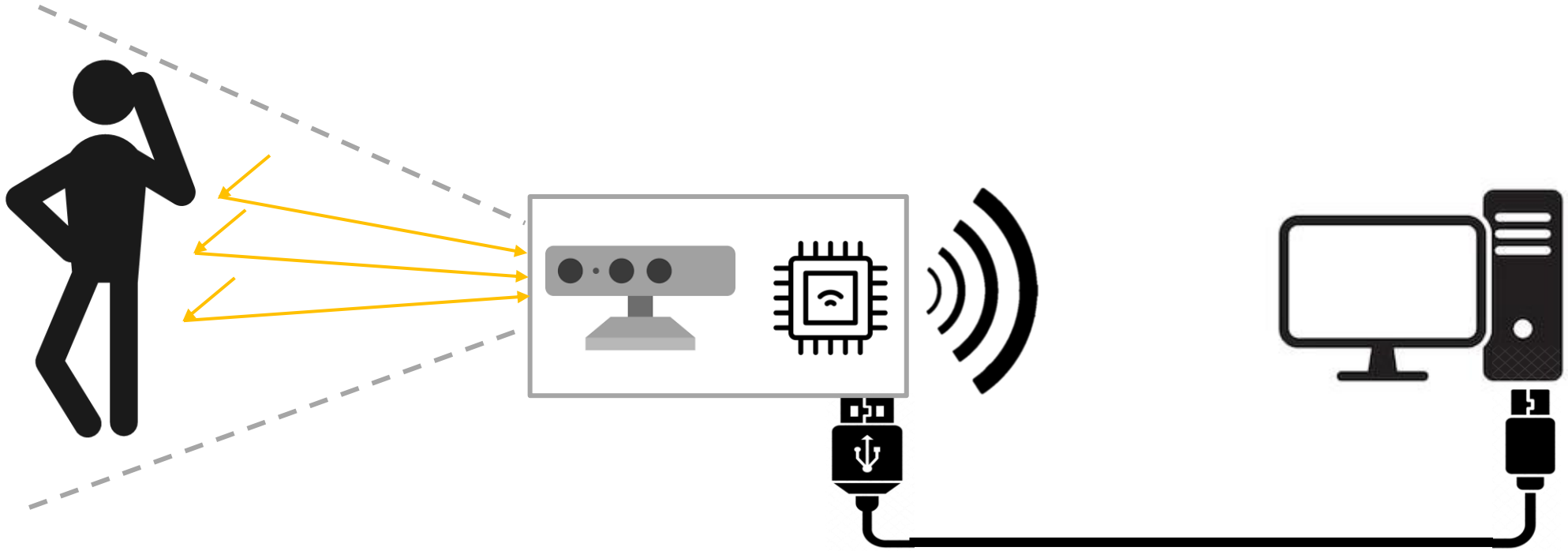
How computers perceive the world

Sensing's role in HCI

- Human-computer Interaction
  - Information exchange between human and computer: Input and Output
- Target
  - Human: voice, gesture, brain wave, … (what did the user do?)
  - Context: time, location, history, … (what does it mean to the user?)
- Goal: understand human (intention and state)



What Does a Sensing System Do?

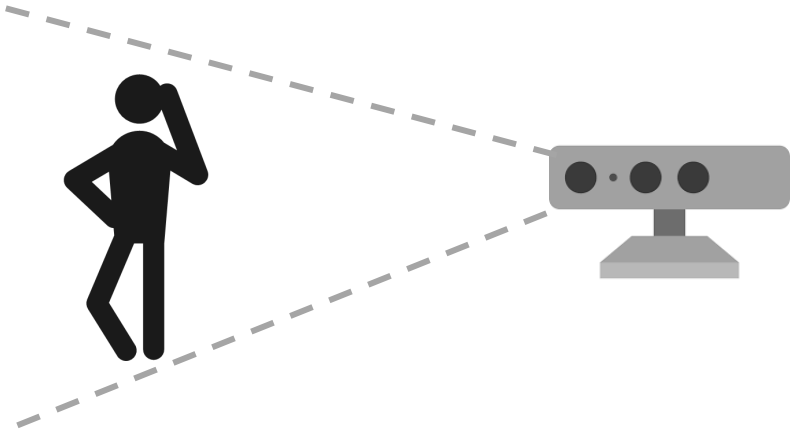


1. **Sense: convert physical quantities (light, sound, etc) to digital data**
2. **Transfer: send data to the computer**
3. **Compute: extract information and knowledge from the data**

Design vs Analysis

Feature Design

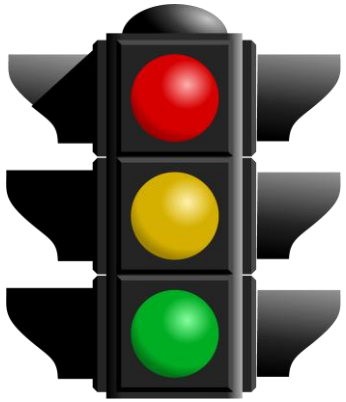
What information is needed to acquire the knowledge?



Signal Analysis

How to acquire knowledge from existing information?

Feature Design Examples (Design for Human)



Traffic lights designed for eyes

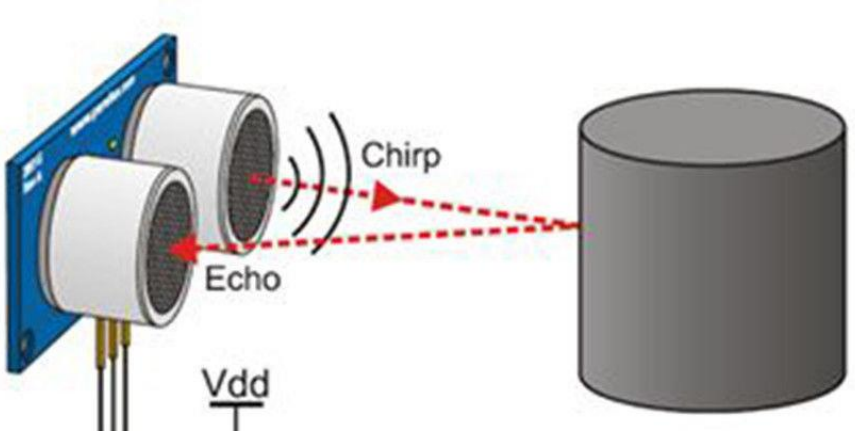
Alarm clock designed for ears

Key grooves designed for fingers

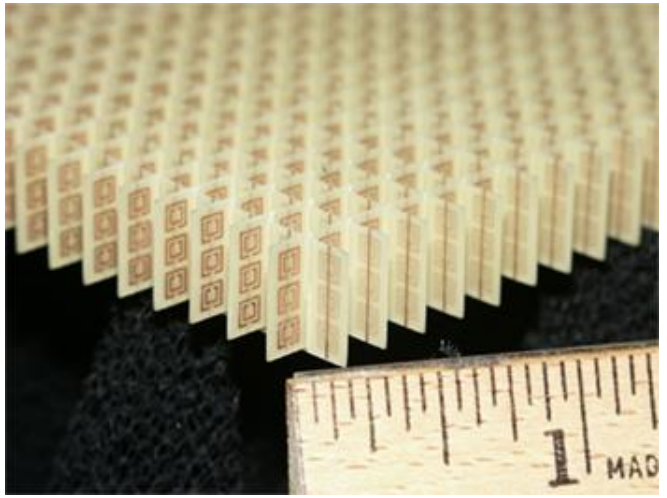
Sensing design in HCI: Design for Computers!

Sensing Design for Computers Examples

QR code



Ultrasonic Proximity Sensor

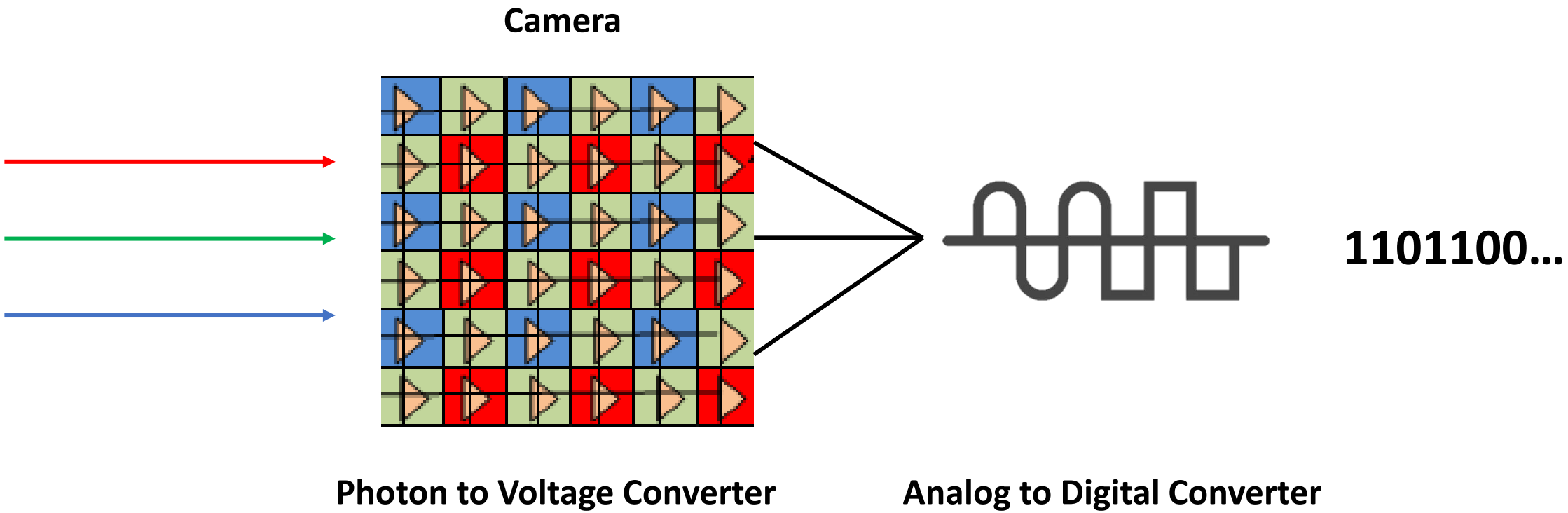


Metamaterial

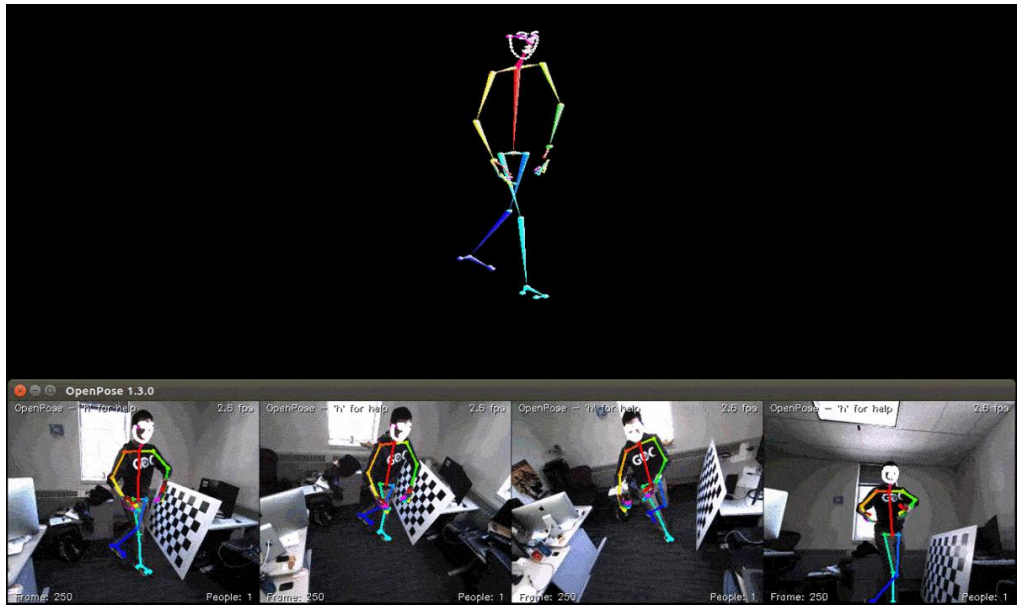
Sensing Systems Categorization

- Signal Type
  - Visual, acoustic, electrical, electromagnetic, …
- Location
  - On-body, off-body
- Schedule
  - Always-on, periodic, on-demand
- …

Visual Signal



Pose Detection

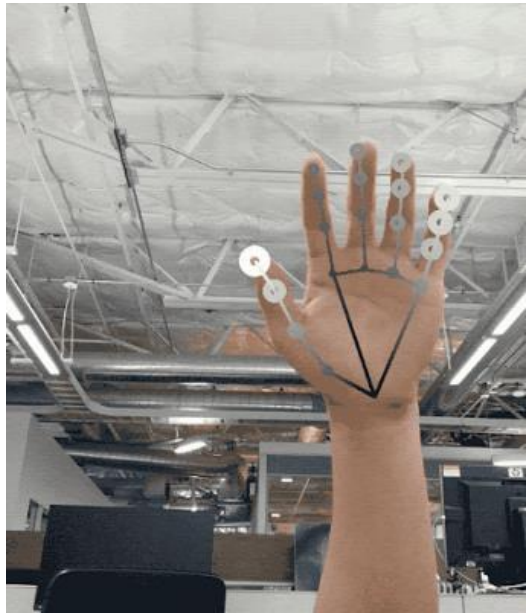


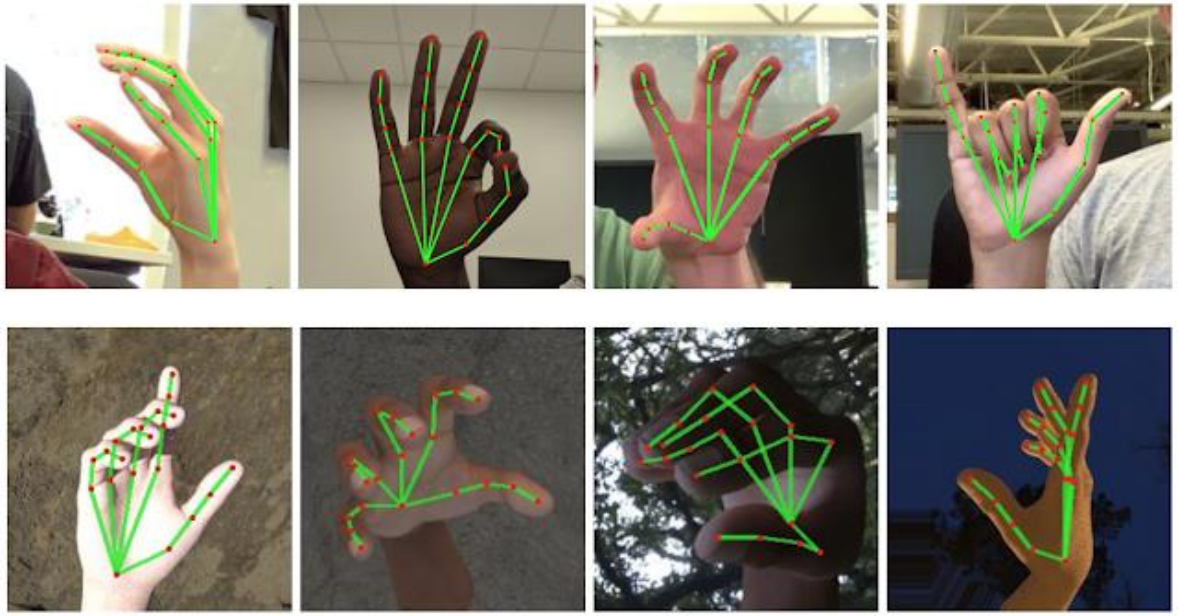
OpenPose

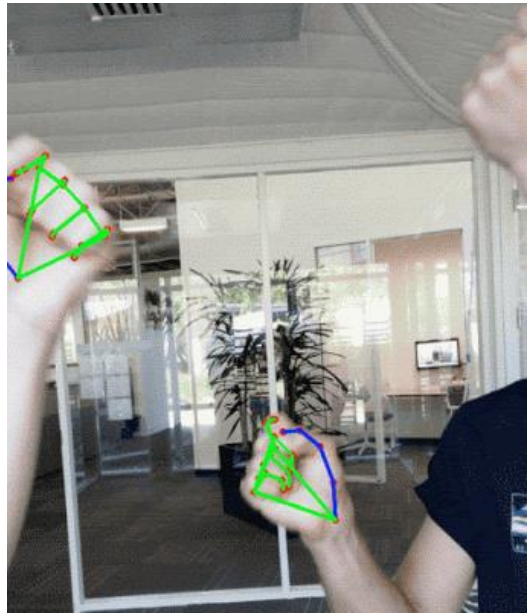
Kinect

https://github.com/CMU-Perceptual-Computing-Lab/openpose

Hand Gesture Detection





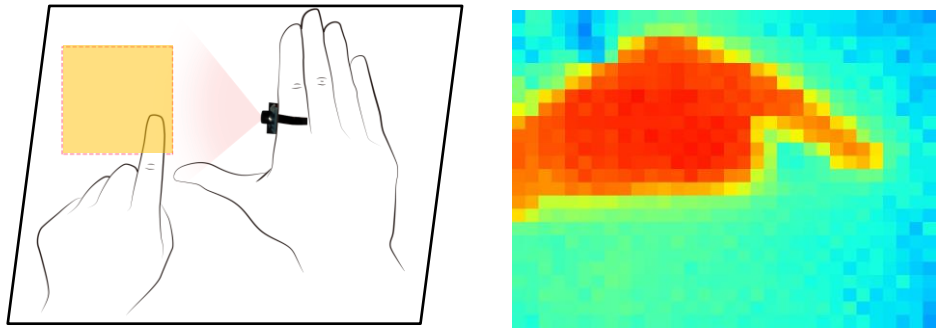


Google MediaPipe

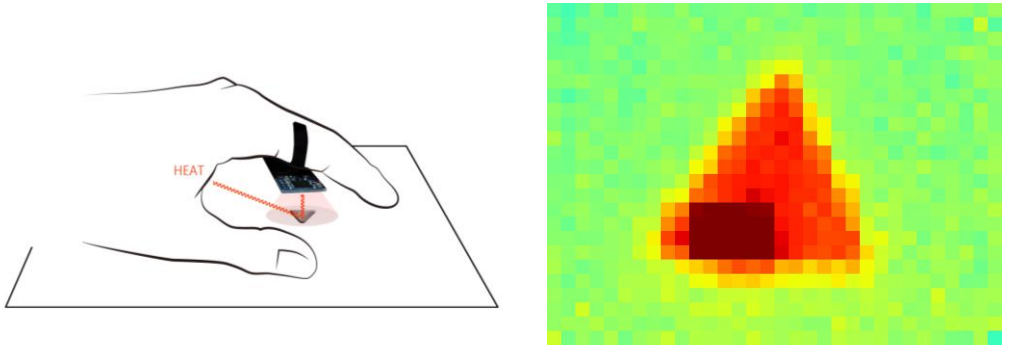
1. On-Device, Real-Time Hand Tracking with MediaPipe, https://ai.googleblog.com/2019/08/on-device-real-time-hand-tracking-with.html

Thermal Imaging

Drawing Gesture Recognition



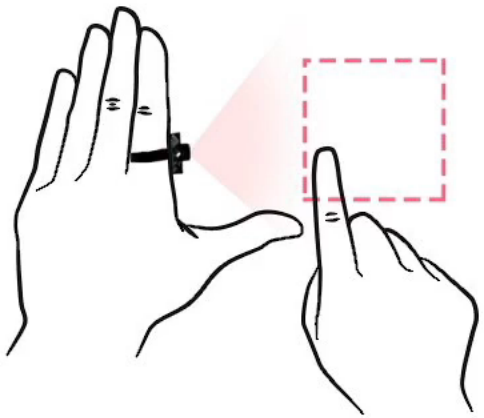
Thermal Tag Identification



Identity-anonymous, illumination-invariant, power-efficient Finger-worn Vision-based Input Technique

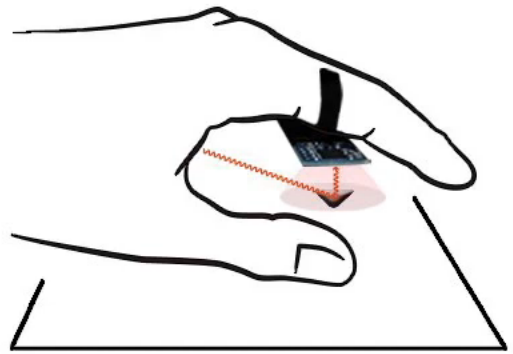
Versatile, Spontaneous, Subtle, Private

1. Tengxiang Zhang, Xin Zeng, Yinshuai Zhang, Ke Sun, Yuntao Wang, and Yiqiang Chen. 2020. ThermalRing: Gesture and Tag Inputs Enabled by a Thermal Imaging Smart Ring. CHI '20, 1–13. https://doi.org/10.1145/3313831.3376323



ThermalRing

Gesture and Tag Inputs Enabled by a Thermal Imaging Smart Ring



Tengxiang Zhang (ztxseuthu@gmail.com), Xin Zeng, Yinshuai Zhang, Ke Sun, Yuntao Wang, Yiqiang Chen

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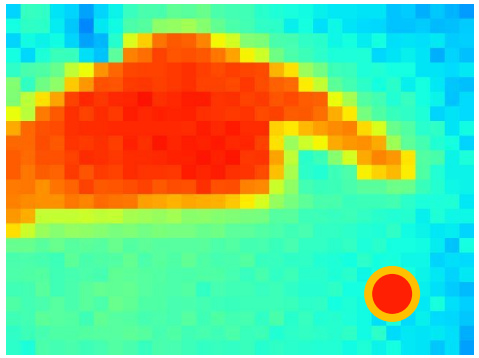
Lenovo

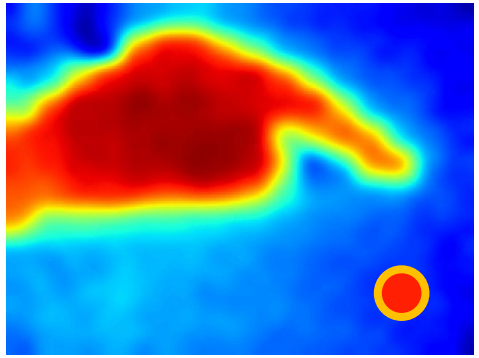
HUAWEI

清華大學 Tsinghua University

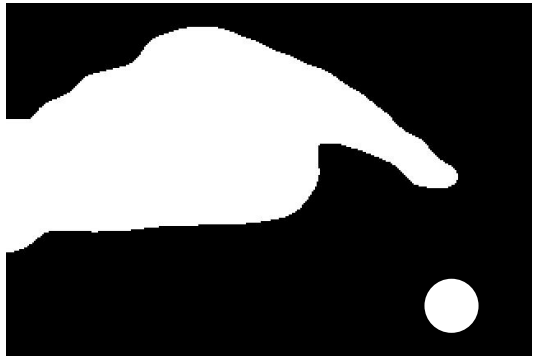
ThermalRing Sensing Pipeline



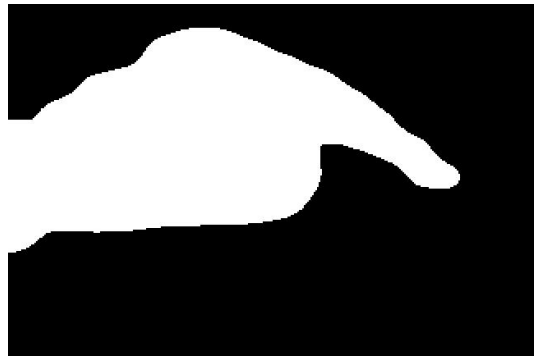
Raw Temperature Data



Scale and Filter



Otsu Thresholding

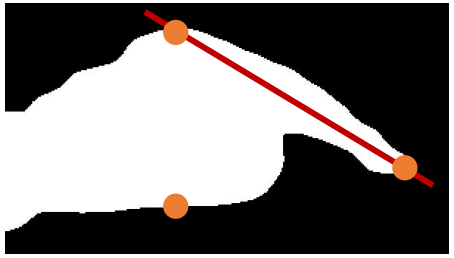


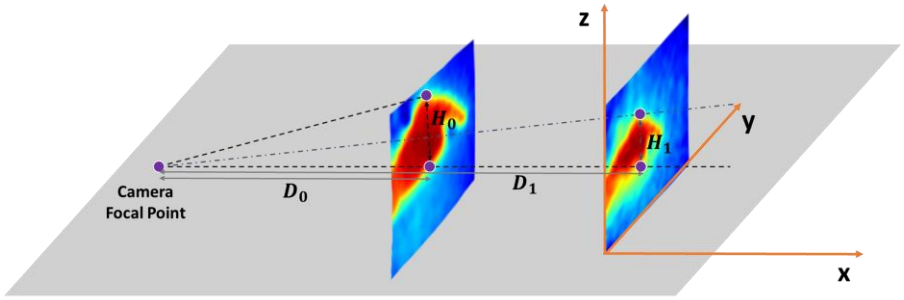
Contour Filter

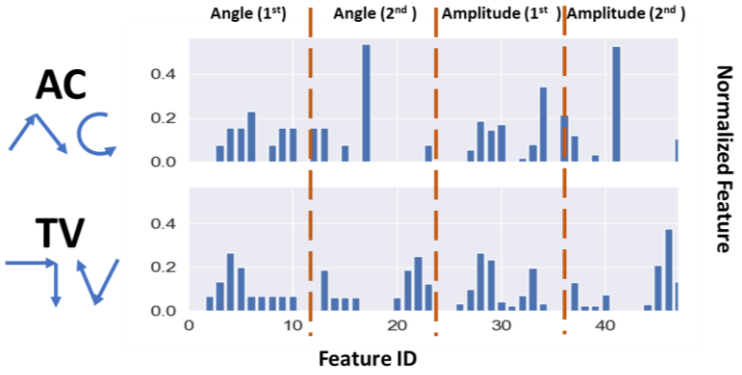
1. Fingertip Extraction
2. Finger Lift Detection

3. X/Y Coordinates Estimation
4. Kalman Filtering

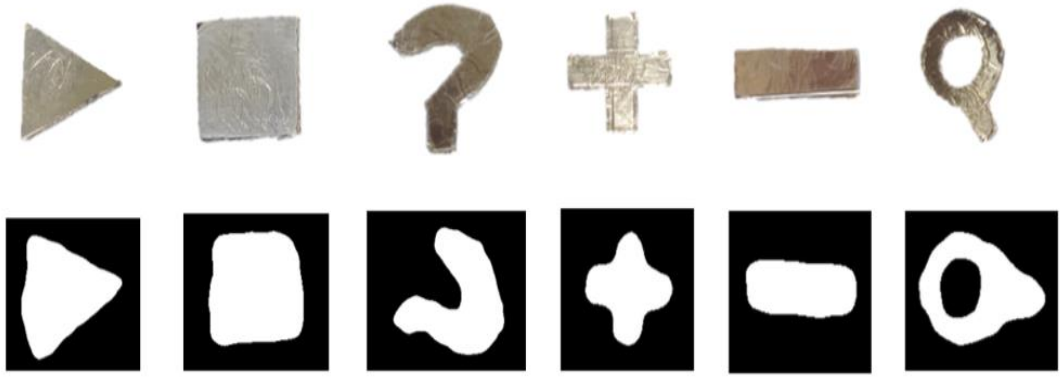
5. BoW Feature Extraction
6. SVM Prediction





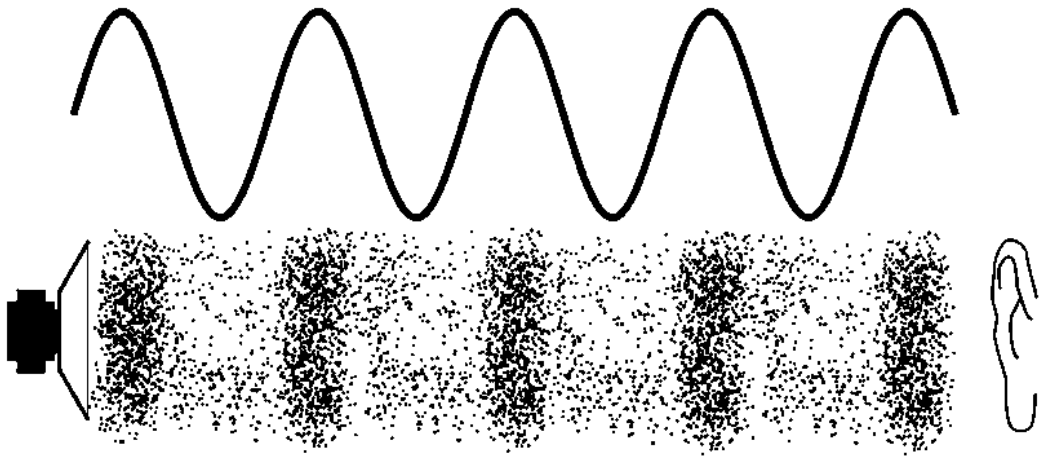


ThermalTag: Sensing Design for Thermal Camera

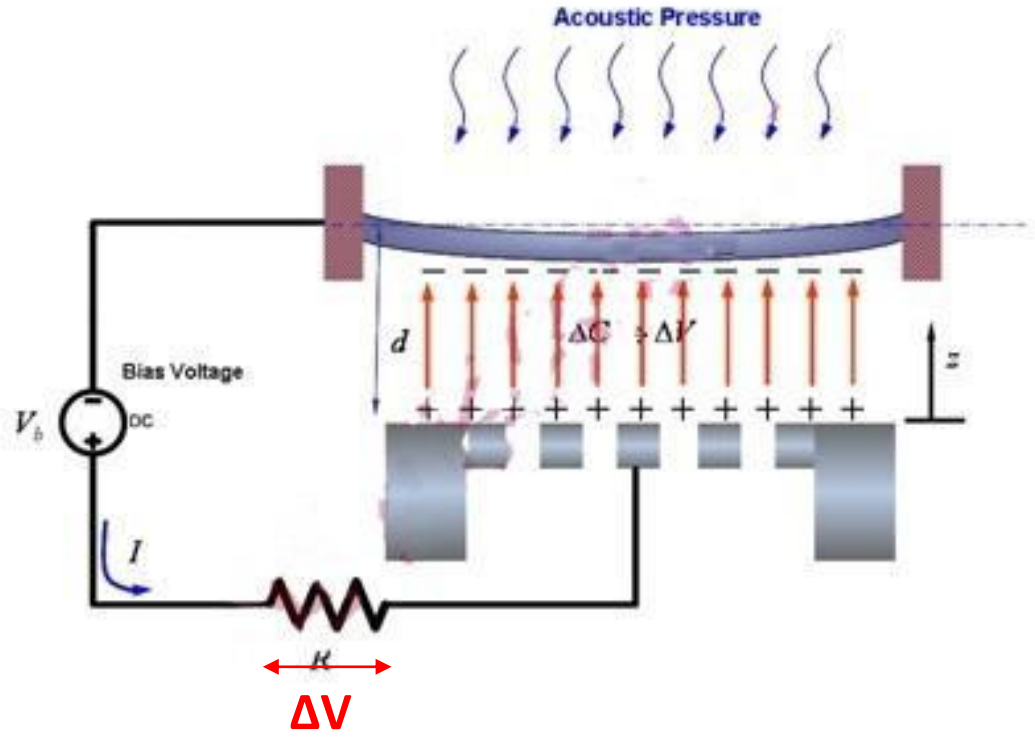


- ThermalTag: Thin and Passive Tags made of high heat reflection materials in DIY manner
- Imaging Principle: ThermalTag reflects heat from the hand
- Sensing: Hu moments + SVM

Acoustic Signal

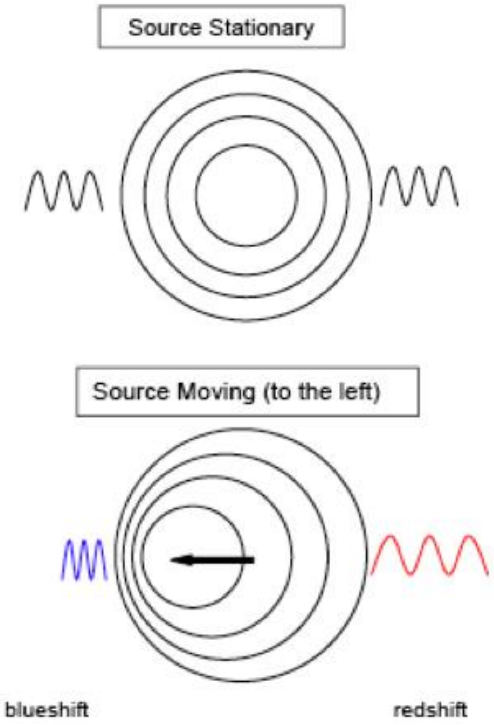


Longitudinal wave
Vibration of Air



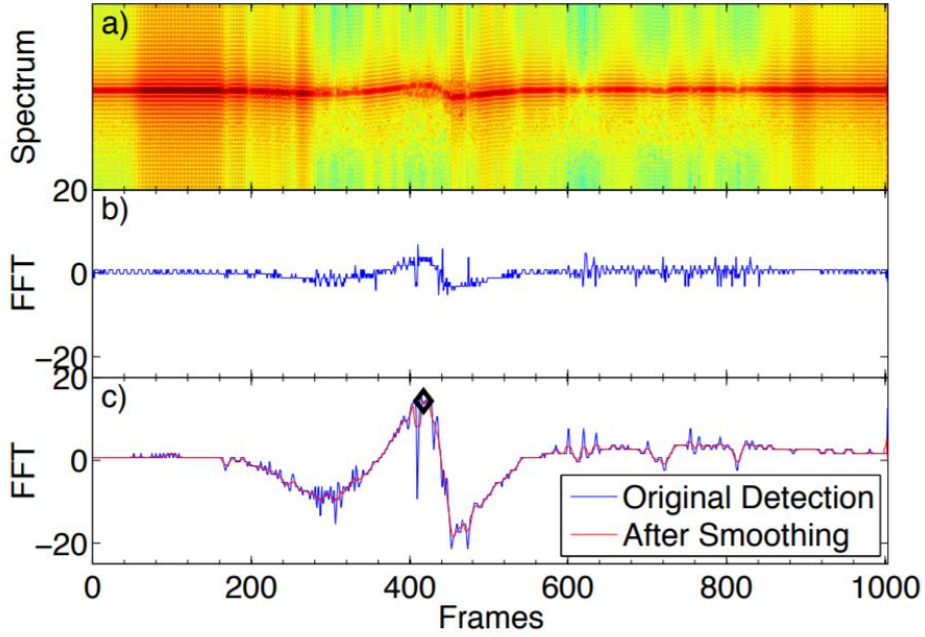
Microphone Principle

Direction Finding



$$f_o = \frac{v + v_o}{v + v_s} f_s$$

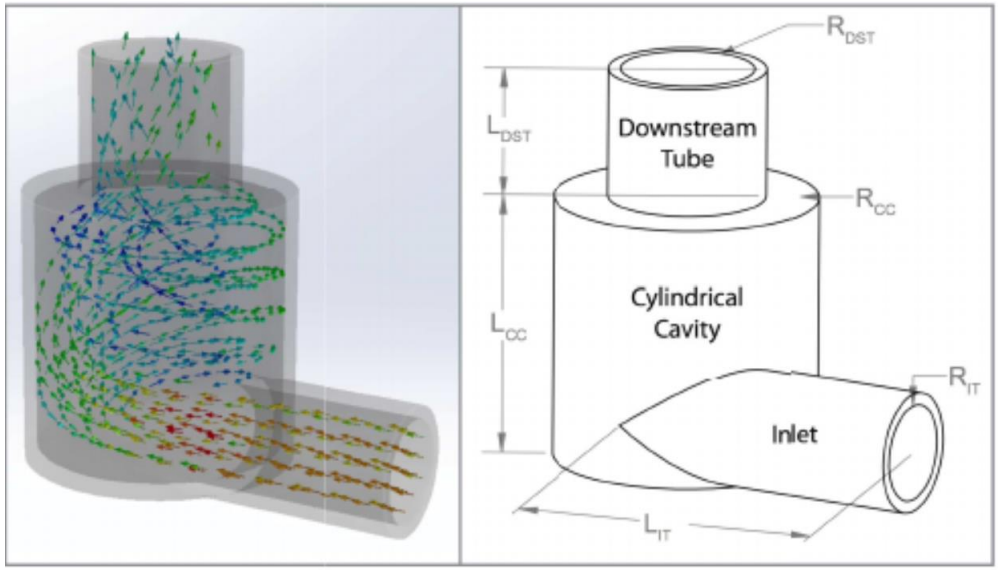
Spartacus



Spectrogram

Zheng Sun, Aveek Purohit, Raja Bose, and Pei Zhang. 2013. Spartacus: spatially-aware interaction for mobile devices through energy-efficient audio sensing. MobiSys '13., 263-276. DOI:https://doi.org/10.1145/2462456.2464437

SpiroCall: Designing Audio Features

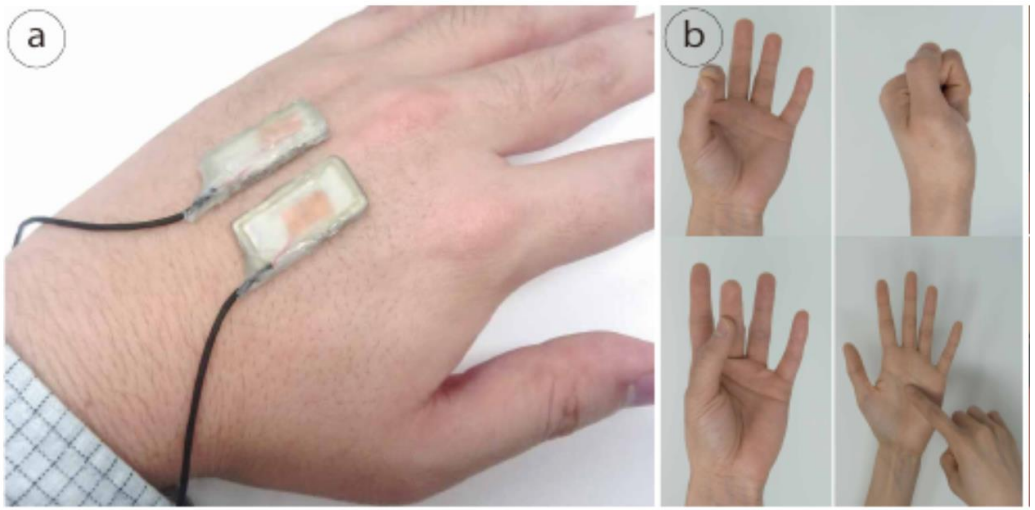


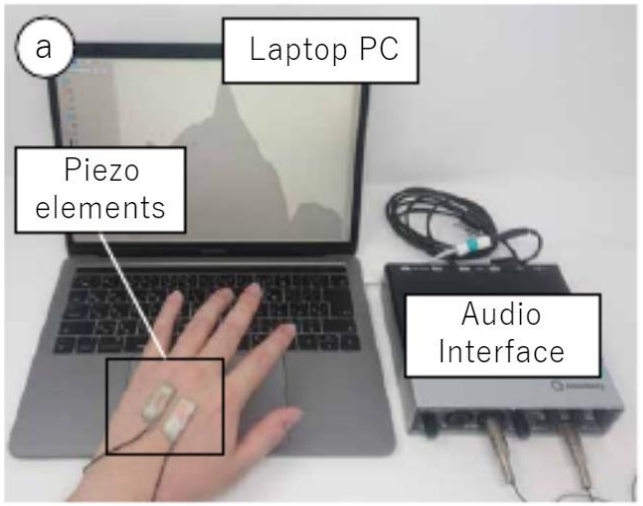
Measuring Lung Functions over a Phone Call

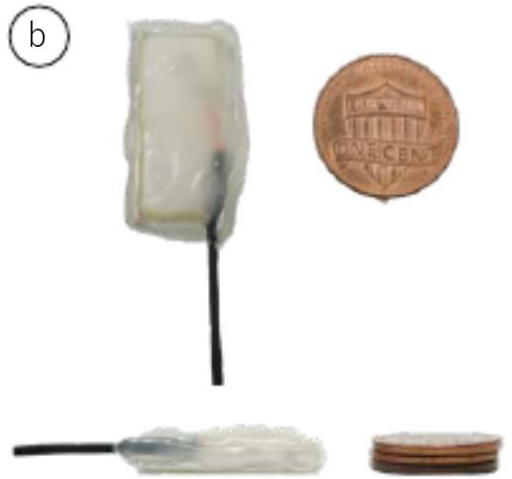
3D printed vortex whistle helps in improving the performance with patients with degraded lung function

Mayank Goel, Elliot Saba, Maia Stiber, Eric Whitmire, Josh Fromm, Eric C. Larson, Gaetano Borriello, and Shwetak N. Patel. 2016. SpiroCall: Measuring Lung Function over a Phone Call.CHI'16, 5675-5685. DOI:https://doi.org/10.1145/2858036.2858401

Surface Acoustic Sensing





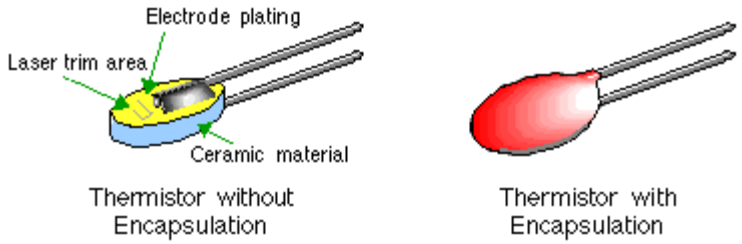


AudioTouch: Sensing hand gestures using a contact speaker and a contact microphone

Yuki Kubo, Yuto Koguchi, Buntarou Shizuki, Shin Takahashi, and Otmar Hilliges. 2019. AudioTouch: Minimally Invasive Sensing of Micro-Gestures via Active Bio-Acoustic Sensing MobileHCI '19. https://doi.org/10.1145/3338286.3340147

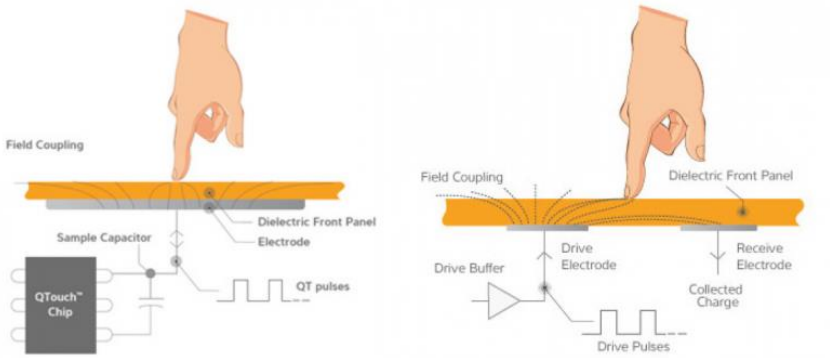
Electrical Signal

Resistive Sensor



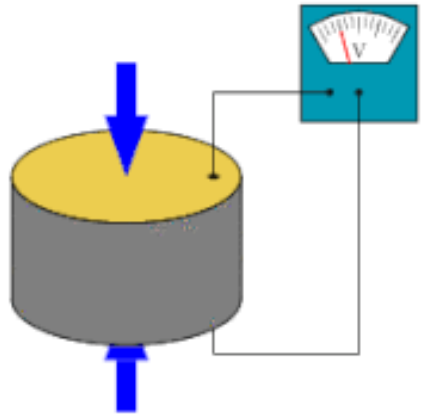
Thermistor

Capacitive Sensor



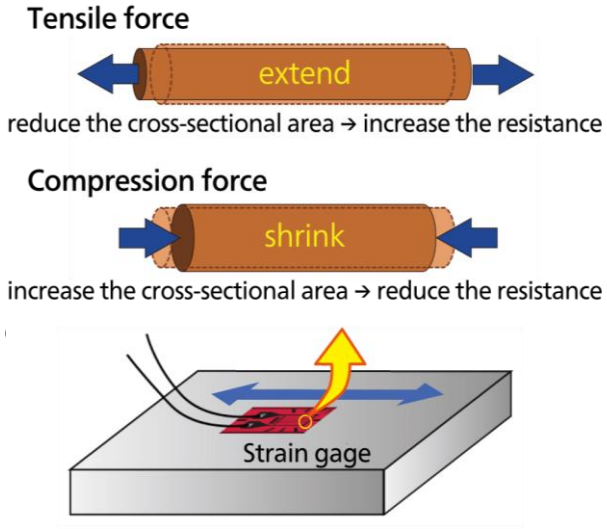
Touch Sensor

Voltage Sensor

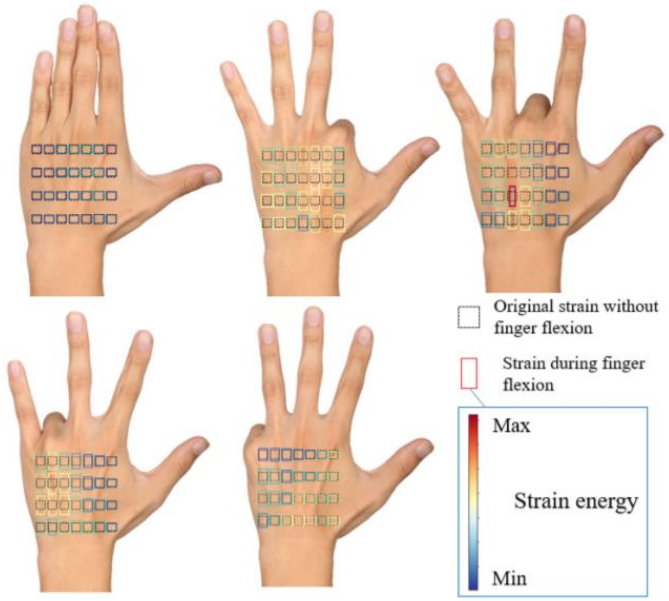


Piezoelectric

On-skin Strain Sensor for Gesture Detection



Resistive Strain Sensor

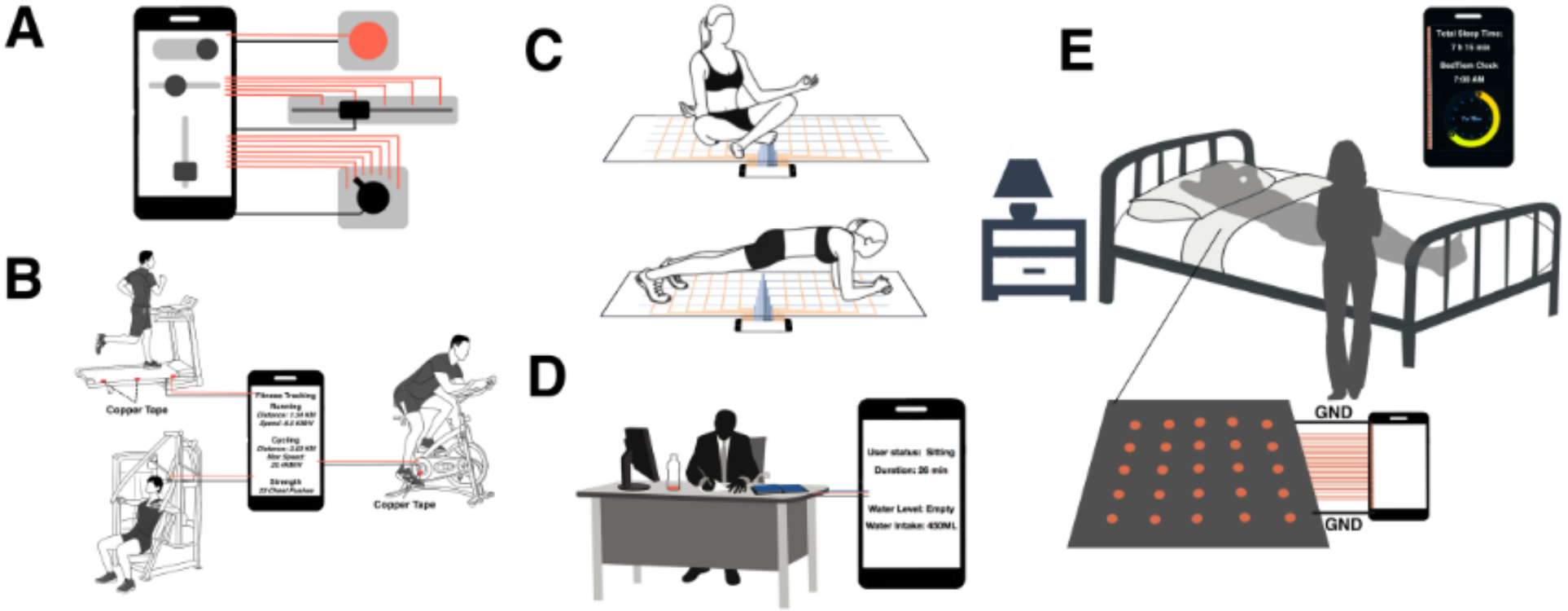


Optimize Sensor Location

Final Placement

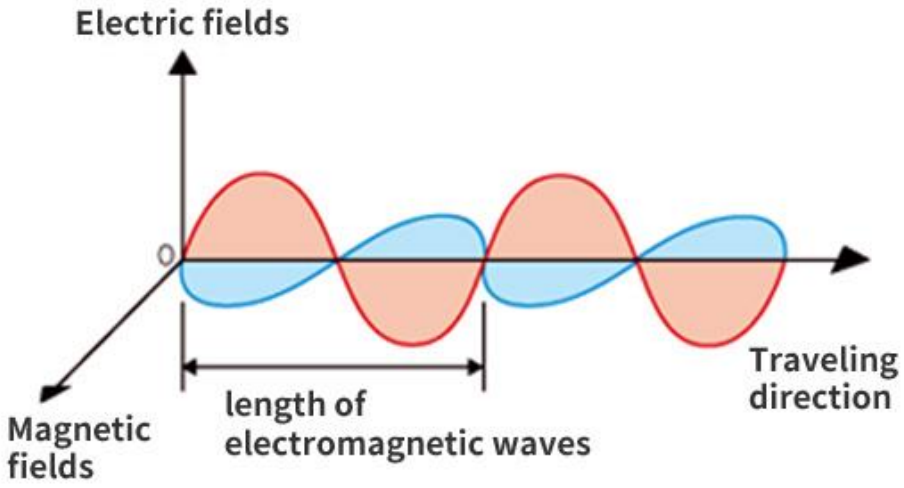
1. Shuo Jiang, Haipeng Xu, and Peter B Shull. 2020. Stretchable e-Skin Patch for Gesture Recognition on the Back of the Hand. *IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS* 67, 1: 11. https://doi.org/10/ghf5vq

FlexTouch: Large Area Capacitive Sensing



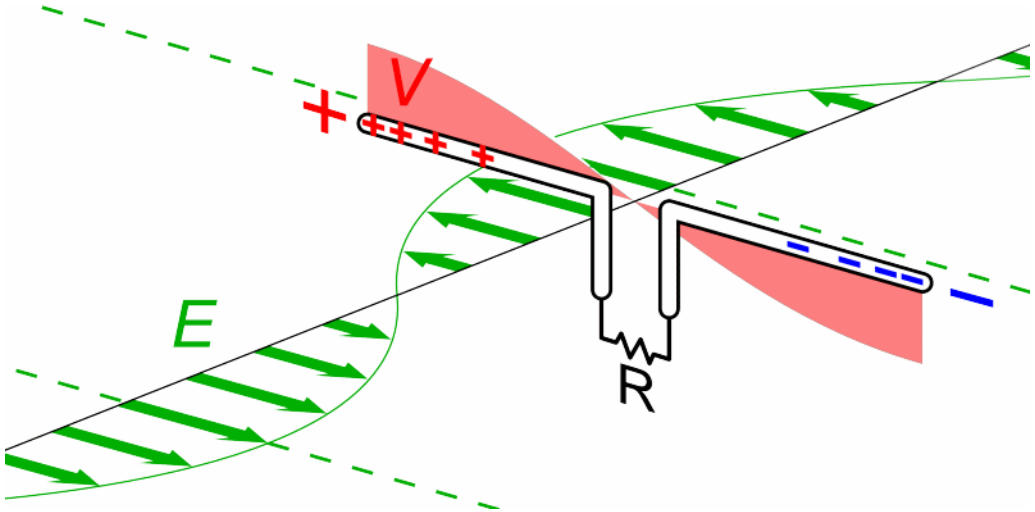
Yuntao Wang, Jianyu Zhou, Hanchuan Li, Tengxiang Zhang, Minxuan Gao, Zhuolin Cheng, Chun Yu, Shwetak Patel, and Yuanchun Shi. 2019. FlexTouch: Enabling Large-Scale Interaction Sensing Beyond Touchscreens Using Flexible and Conductive Materials. *IMWUT.* 3, 3: 109:1-109:20. https://doi.org/10.1145/3351267

Electromagnetic Signal



Transverse wave

Amplitude, Phase, Frequency, Polarization



Antenna

Converter electric field to current

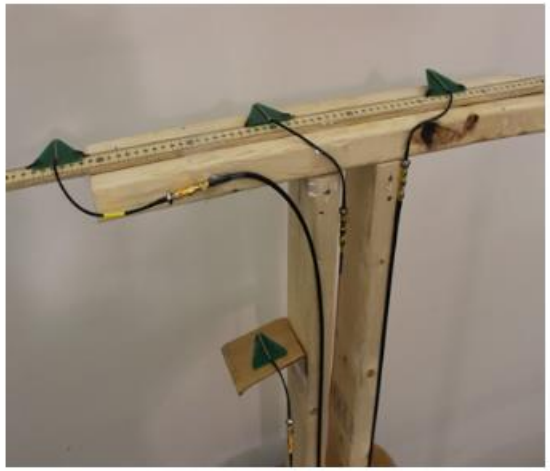
https://en.wikipedia.org/wiki/Dipole_antenna

RF-Pose3D

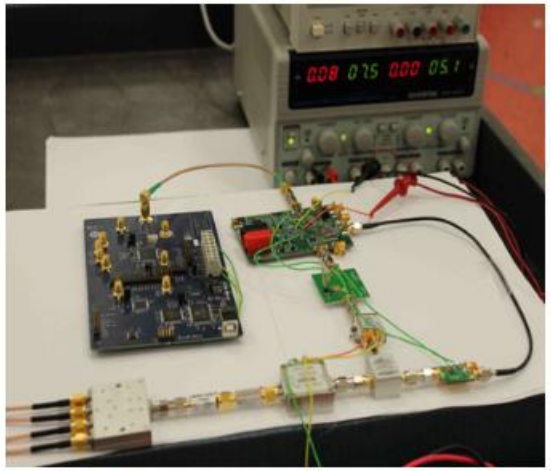
Multi-person 3D pose reconstruction

RF-Based 3D Skeletons, *Mingmin Zhao, Yonglong Tian, Hang Zhao, Tianhong Li, Mohammad Abu Alsheikh, Rumen Hristov, Zachary Kabelac, Dina Katabi, Antonio Torralba. ACM SIGCOMM, 2018*

RF-Pose3D

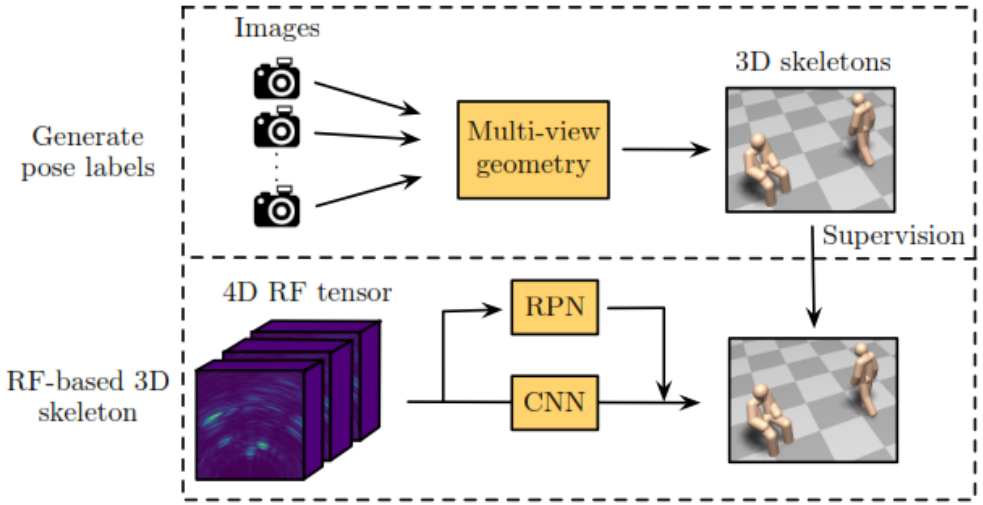


(a) **Antenna "T" Setup**



(b) **FMCW Signal Generation**

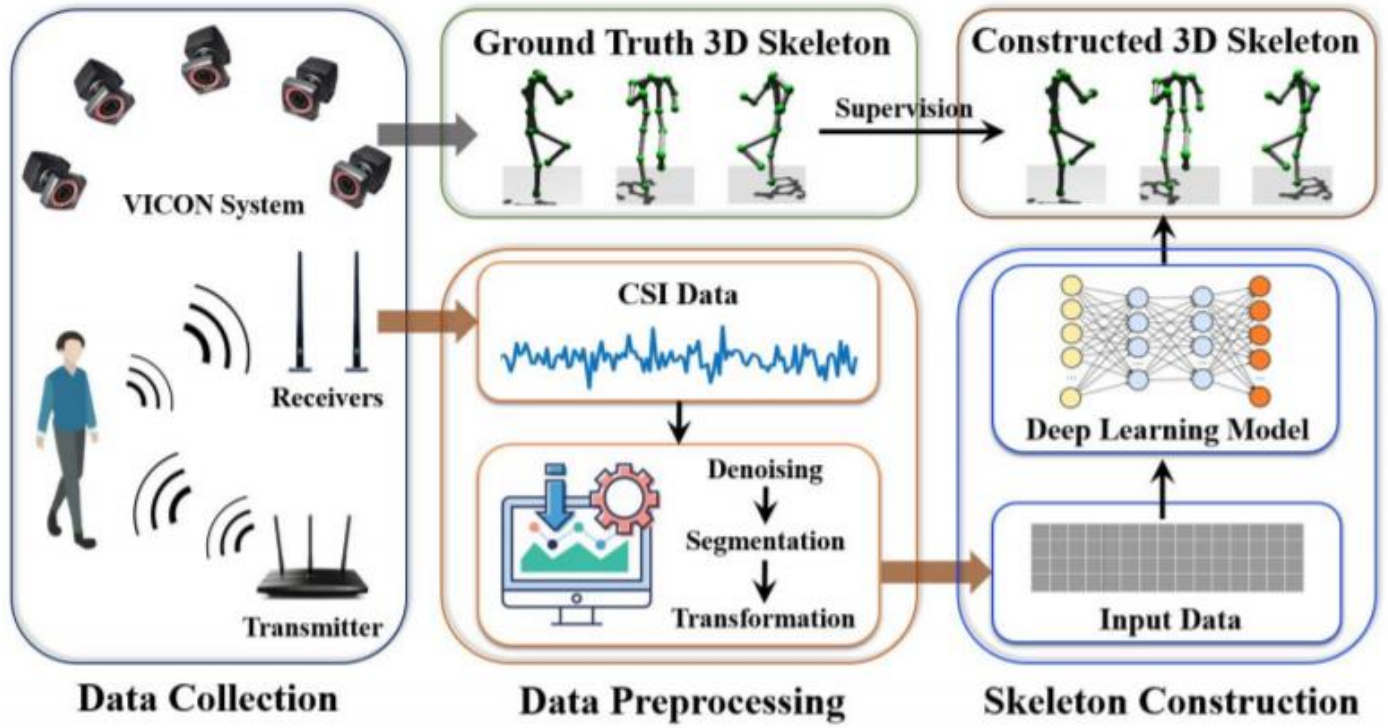
Equipment Setup



Sensing Method

1. Fadel Adib, Zach Kabelac, Dina Katabi, and Robert C. Miller. 2014. 3D Tracking via Body Radio Reflections. 317–329. Retrieved June 28, 2019 from https://www.usenix.org/node/179792

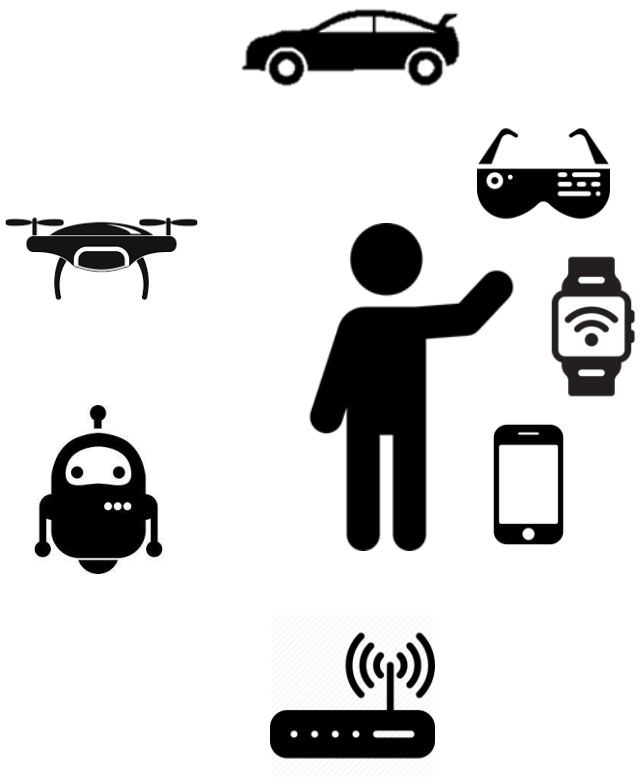
3D Human Pose Construction Using WiFi



Wenjun Jiang, Hongfei Xue, Chenglin Miao, Shiyang Wang, Sen Lin, Chong Tian, Haochen Hu, Zhi Sun, and Lu Su. 2020. Towards 3D Human Pose Construction Using WiFi. 14. https://doi.org/10/gg88k6

Tagging Everyday Things

Computer
Resource-redundant

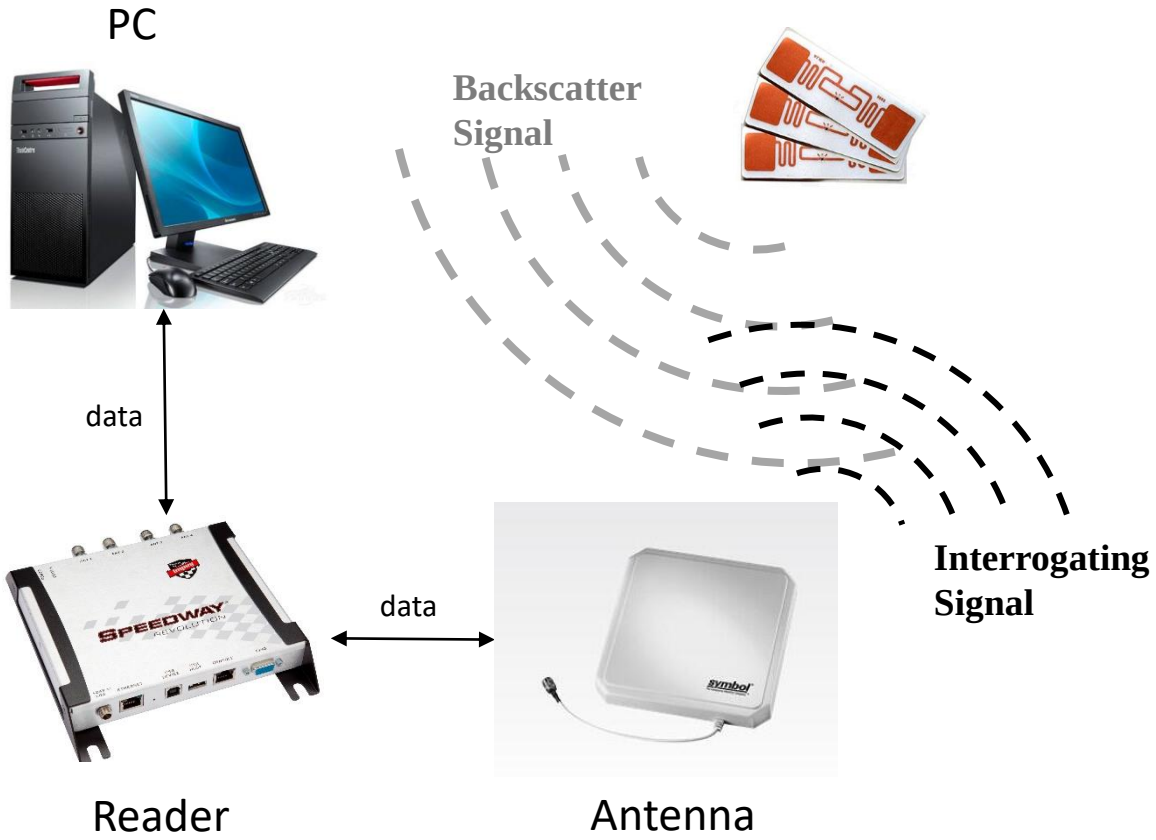


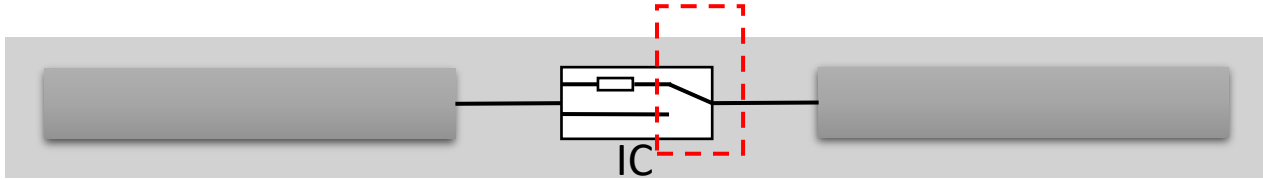
Interconnection

Power
Information

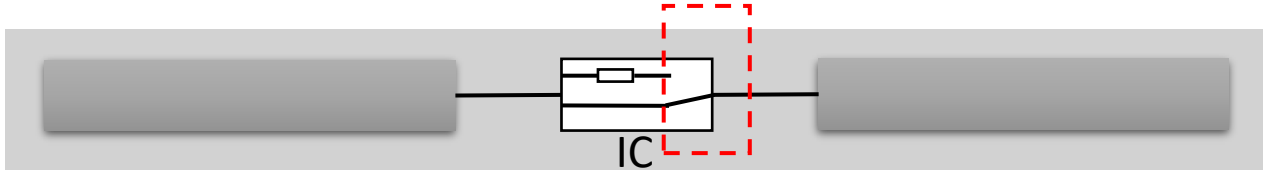
Thing
Resource-constrained

RFID Working Principle





Match



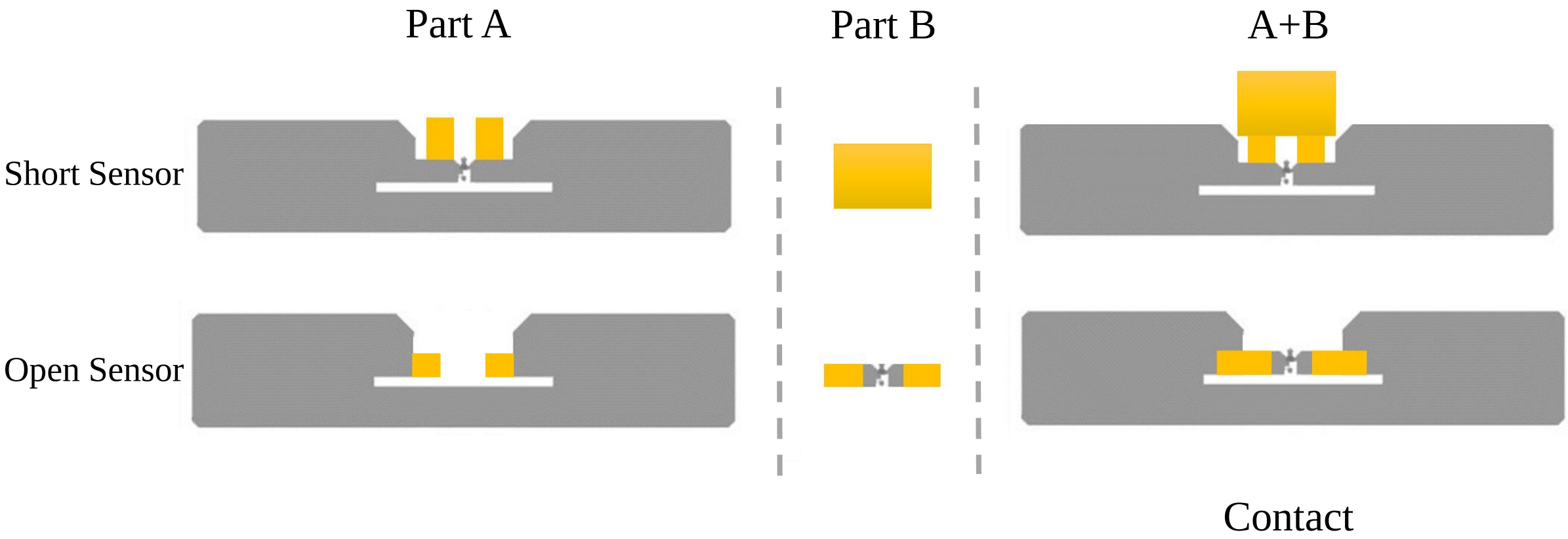
Mismatch

Differential Radar Cross Section

$$\Delta\sigma = \frac{\lambda^2 G^2}{4\pi} |\Gamma_1^2 - \Gamma_2^2|$$

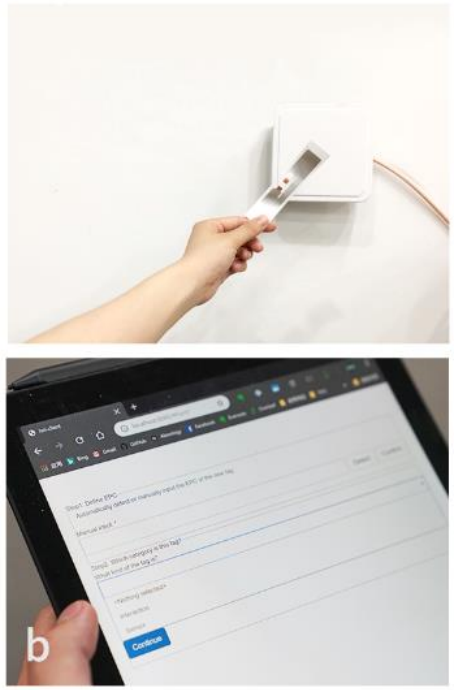
User DIYed Backscatter Sensor: BitID

BitID Sensor



Usage of BitID

Manufacture



Registration
and Definition

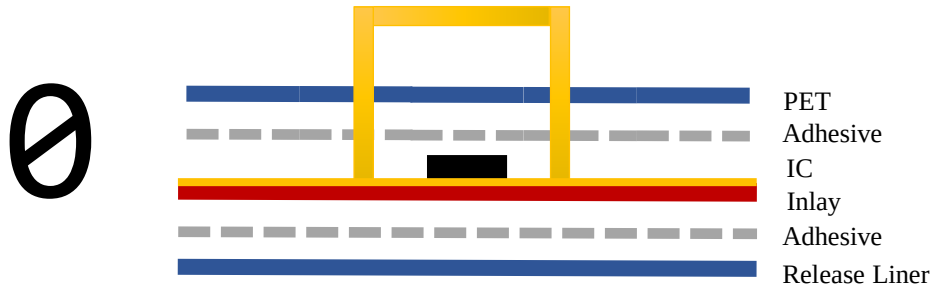
Deployment

Feedback

Sensing Principle

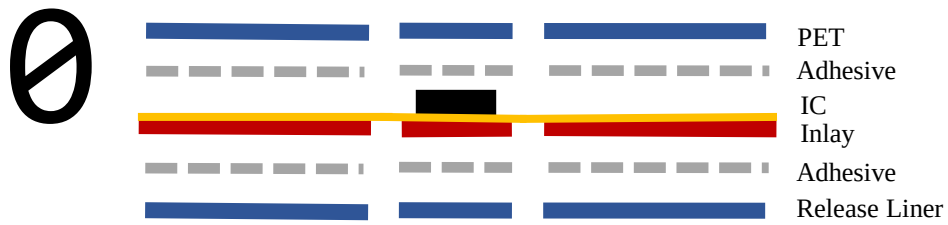
Differential Radar Cross Section $\Delta\sigma = \frac{\lambda^2 G^2}{4\pi}|\Gamma_1^2 - \Gamma_2^2|$

Short



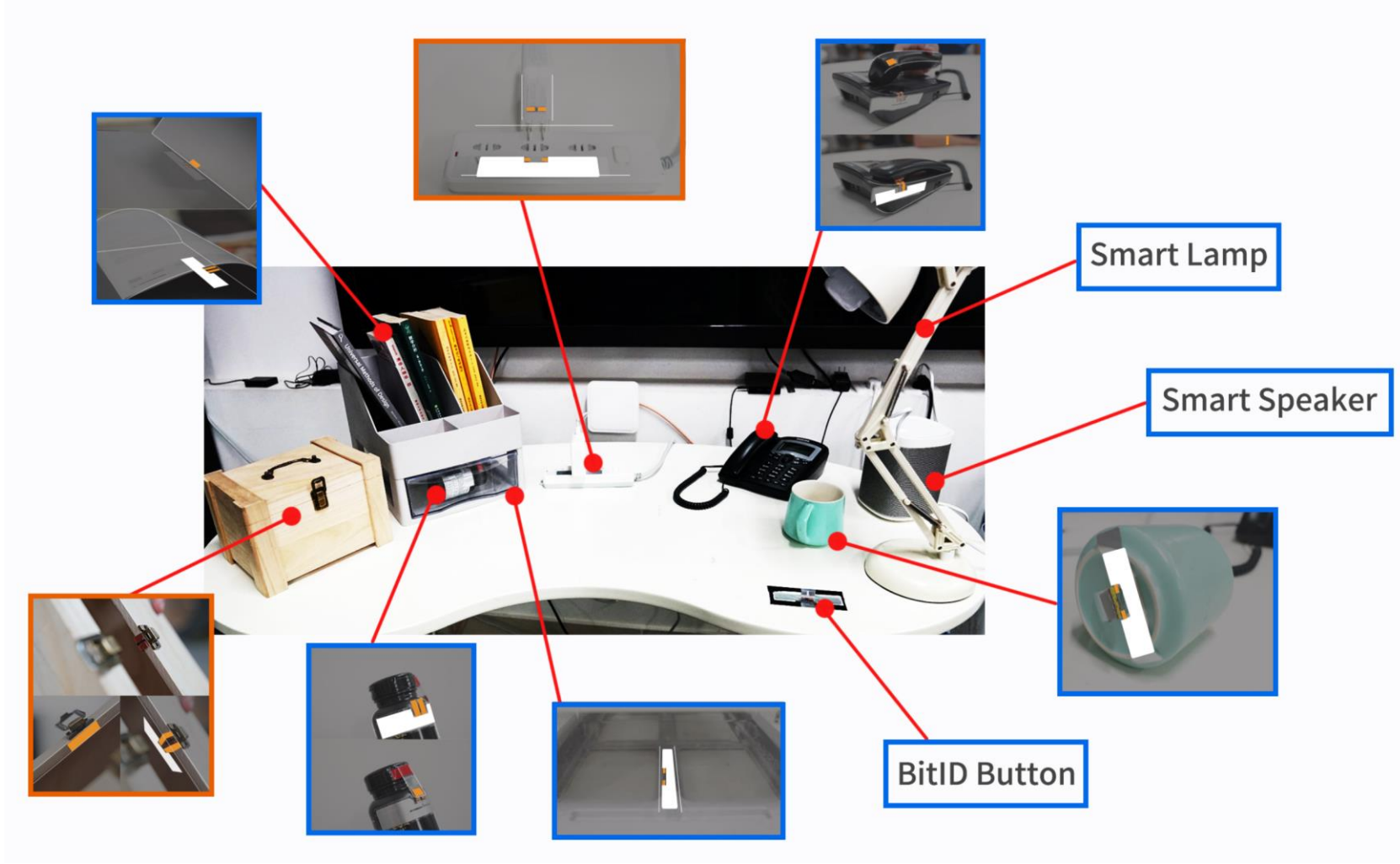
$\Gamma_1 \approx \Gamma_2 \rightarrow \Delta\sigma \approx 0$

Open



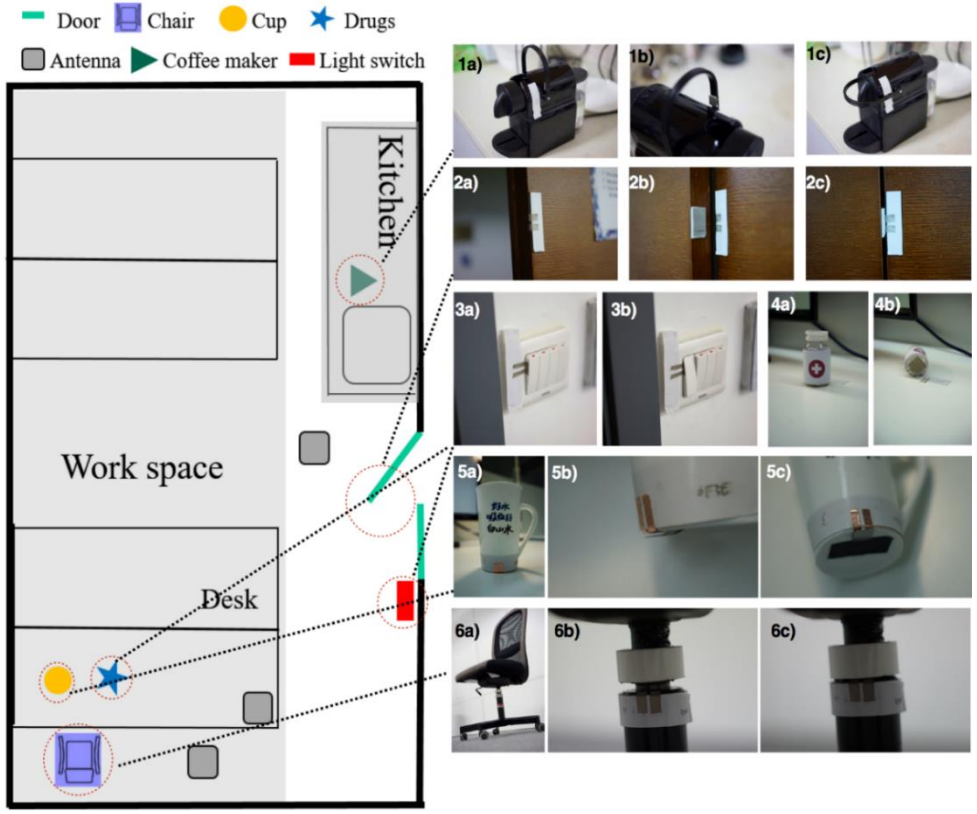
$$\begin{cases} \Gamma_1 \approx \Gamma_2 \\ G \approx 0 \end{cases} \rightarrow \Delta\sigma \approx 0$$

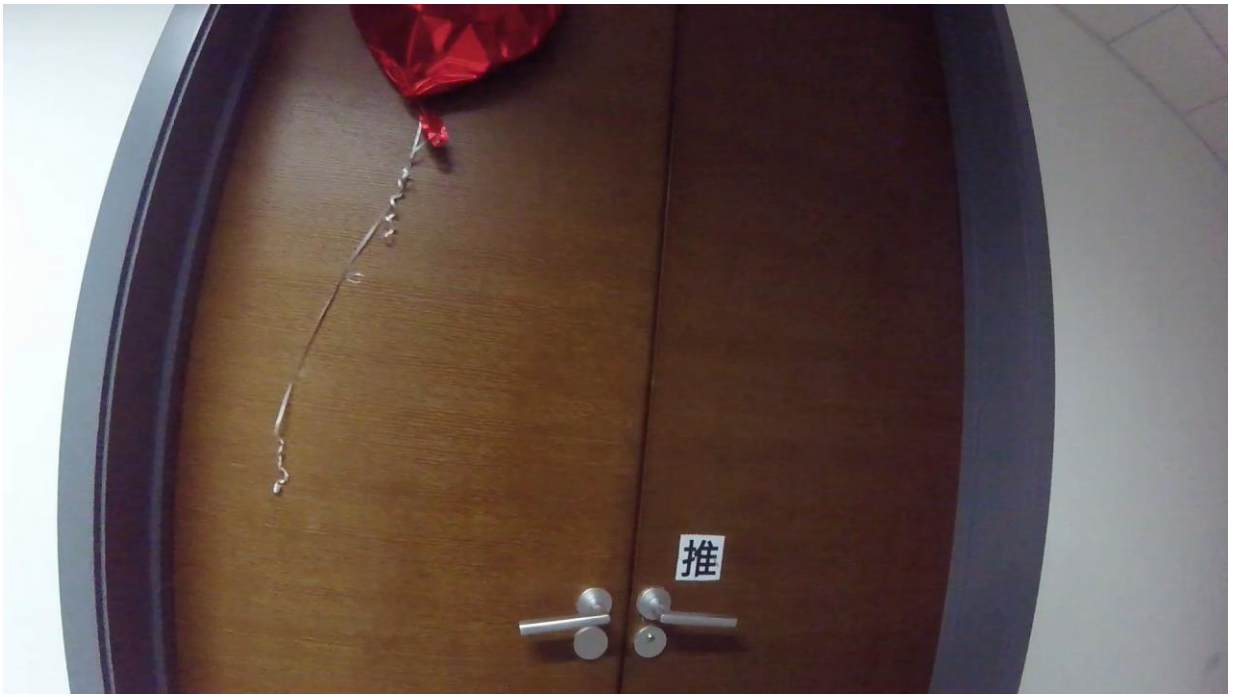
User Study: Evaluating Desktop Applications



- 12 participants (9M3F), Mean Age = 22.1
- 7 Sensing tags, 1 interactive tag
- Watch Video to learn the registration and definition procedure
- 2 deployment tasks (Orange)
  - Charger
  - Box
- 4 behavior tasks (blue)

Room Scale Applications





Drug
Coffee maker
Light Switch
Door
Chair
Cup

Conclusion

- Goal of sensing in HCI: understand human
  - Explicit: voice, movement
  - Implicit: context
- Sensing design is as important as analysis!
  - Pick the right signal
  - Getting the job done properly ≠ fancy deep learning models

Thanks!

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