RF-Wear

Wearable Everyday Body-Frame Tracking using Passive RFIDs

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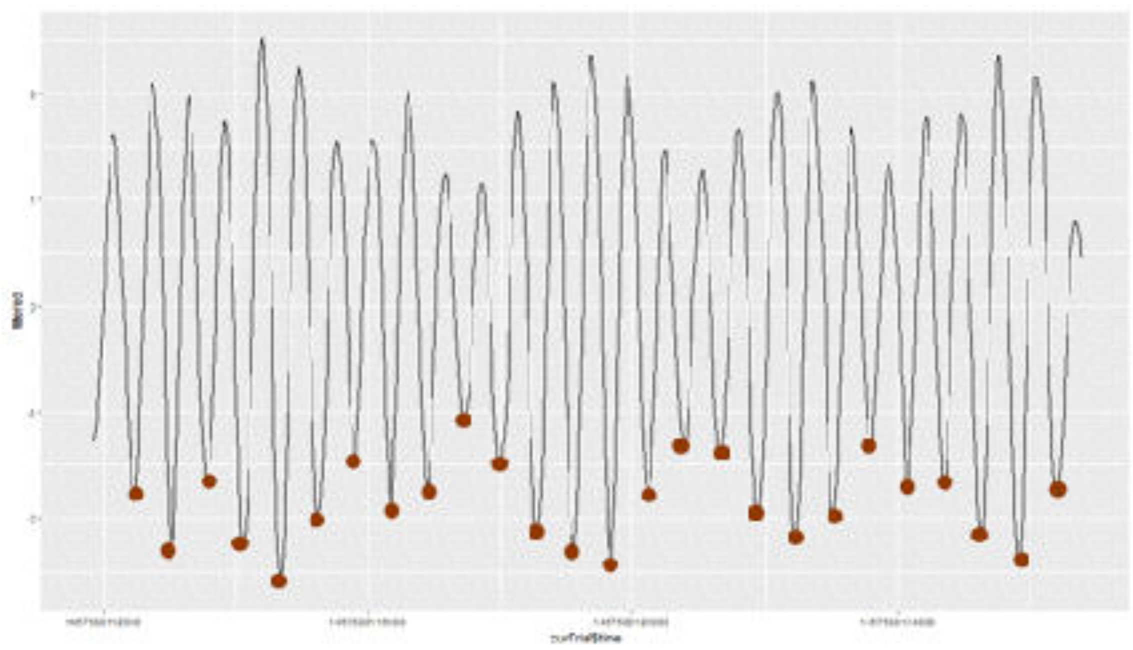
RF-Wear turns a regular clothing into a body-frame aware garment using **low-cost**, **light weight**, **machine washable**, **battery-free** RFID tags.

Commercial Tracking Wearables

How do these devices track?

Pulse Sensor

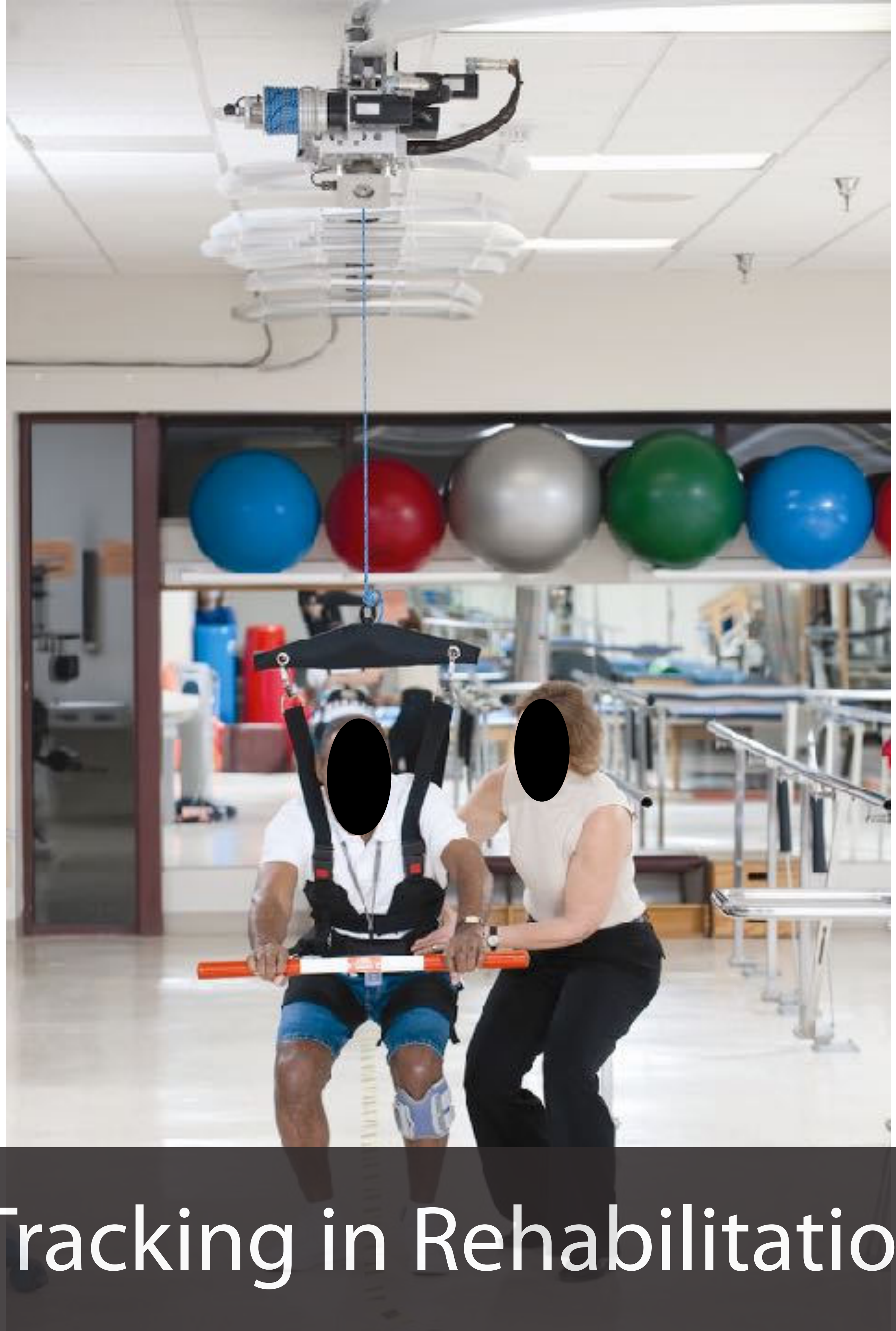
+



Pedometer (Accelerometer)

many times, we want more than
heart rate and steps….

Personal Trainer in Fitness



Gait Tracking in Rehabilitation

Gesture Input in VR/AR

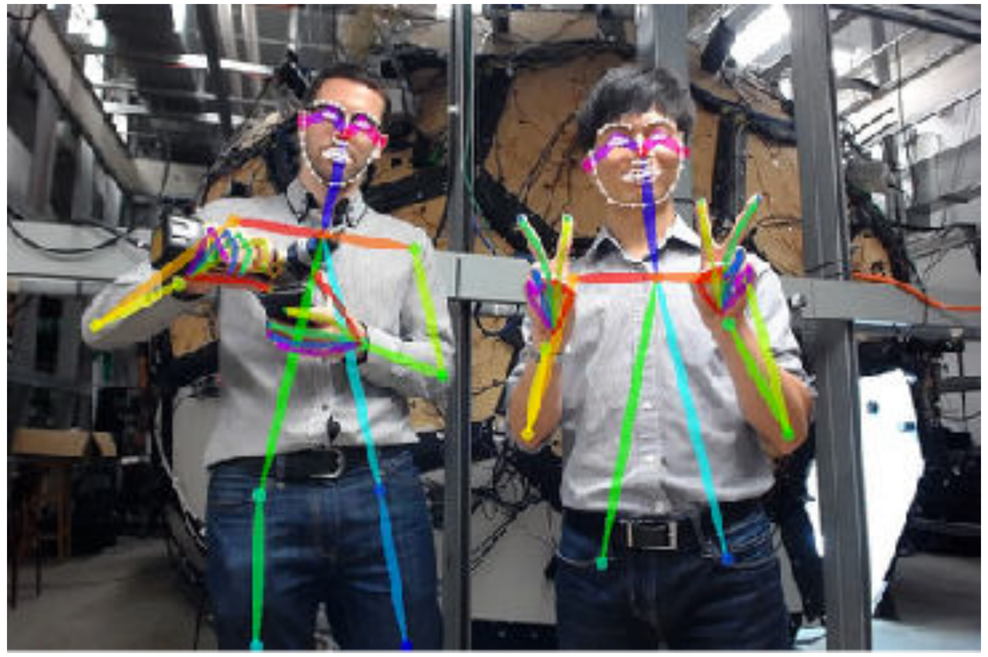
how can we do body-frame today?

Optitrack

Infrastructure-based sensing

Kinect

Leap Motion



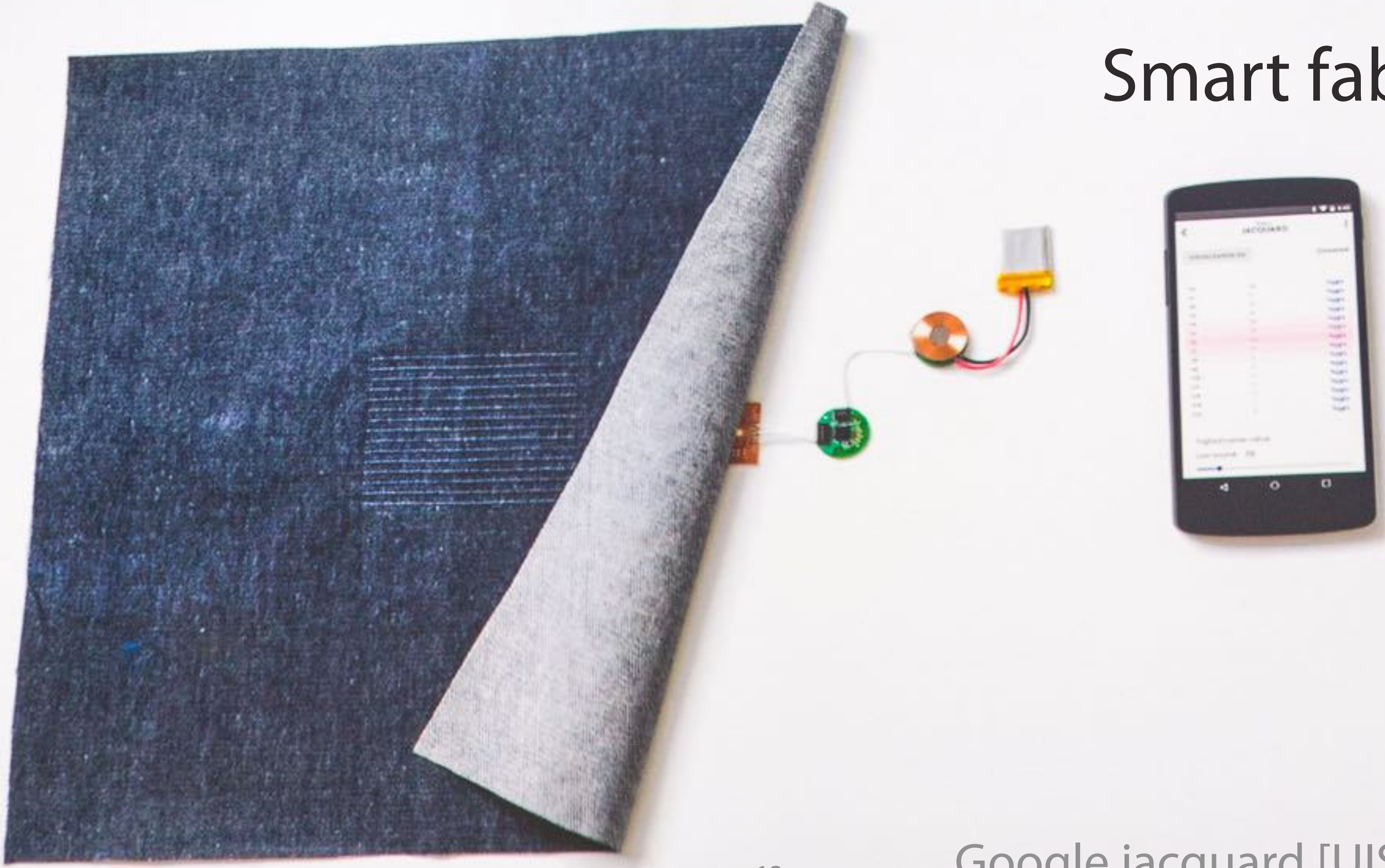
Openpose (CMU)

Wearable Electronics

inertial sensors

Neuron

Smart fabrics



Google jacquard [UIST 2016]

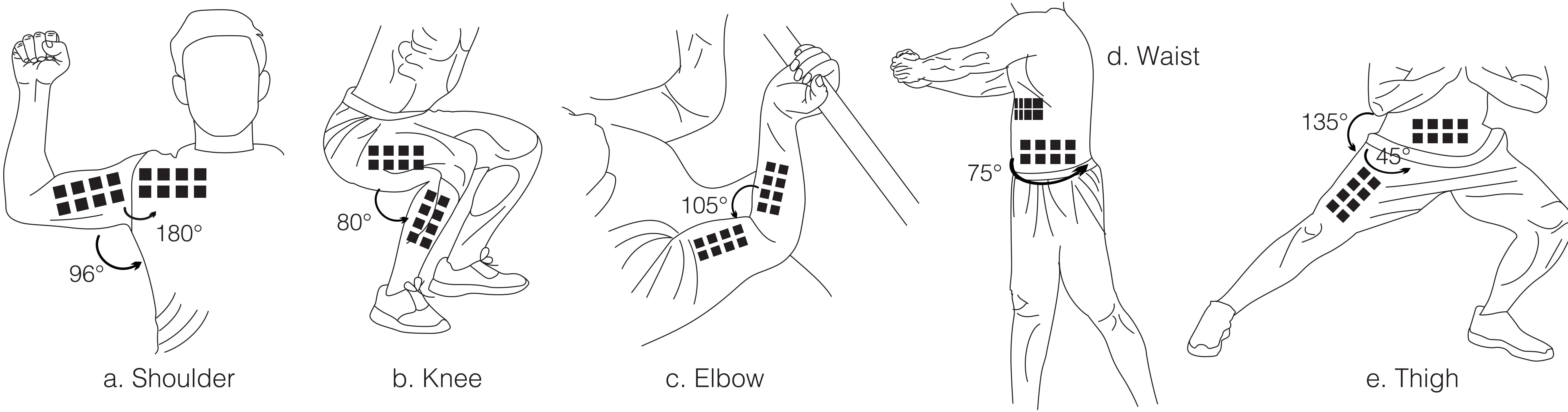
RF-Wear

mobile, ad-hoc	v.s. infrastructure solutions
washable, durable, low cost	v.s. wearable electronics
continuous rich tracking	v.s. smart fabrics (limited gestures)

RF-Wear

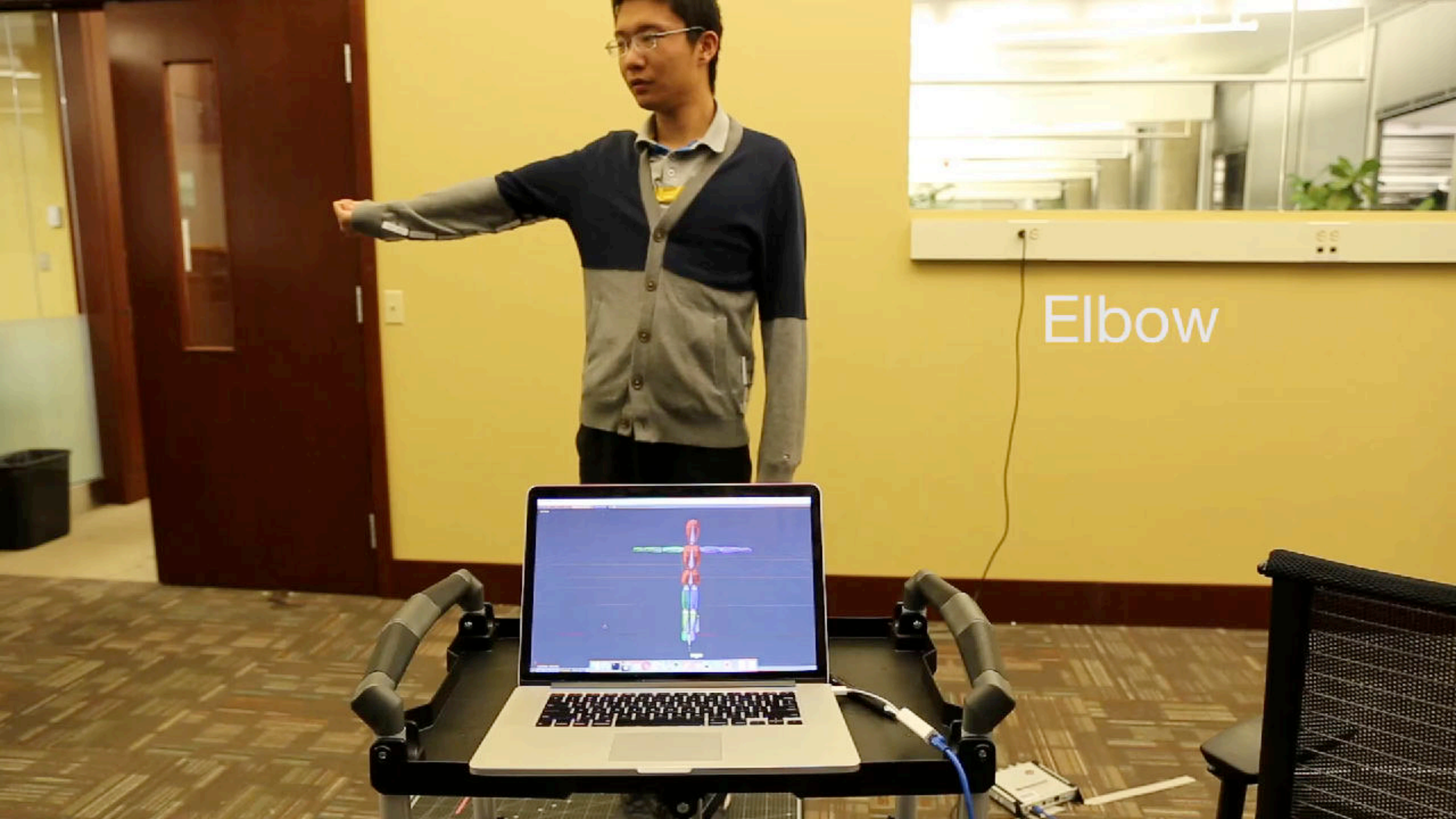
skeleton tracking for daily use.

using low-cost, machine washable, lightweight, battery-free RFIDs



RF-Wear:

average joint angle tracking accuracy of 8~21°, 20~60 Hz


Elbow

research contributions

1 A fine-grained **mobile** RFID tag positioning

2 A RFID sensing primitive for joint tracking

3 A practical body-worn RFID tag placement solution

4 A detailed prototype implementation and evaluation

background

RFID sensing, phase measurement, triangulation

RFID Sensing Configuration

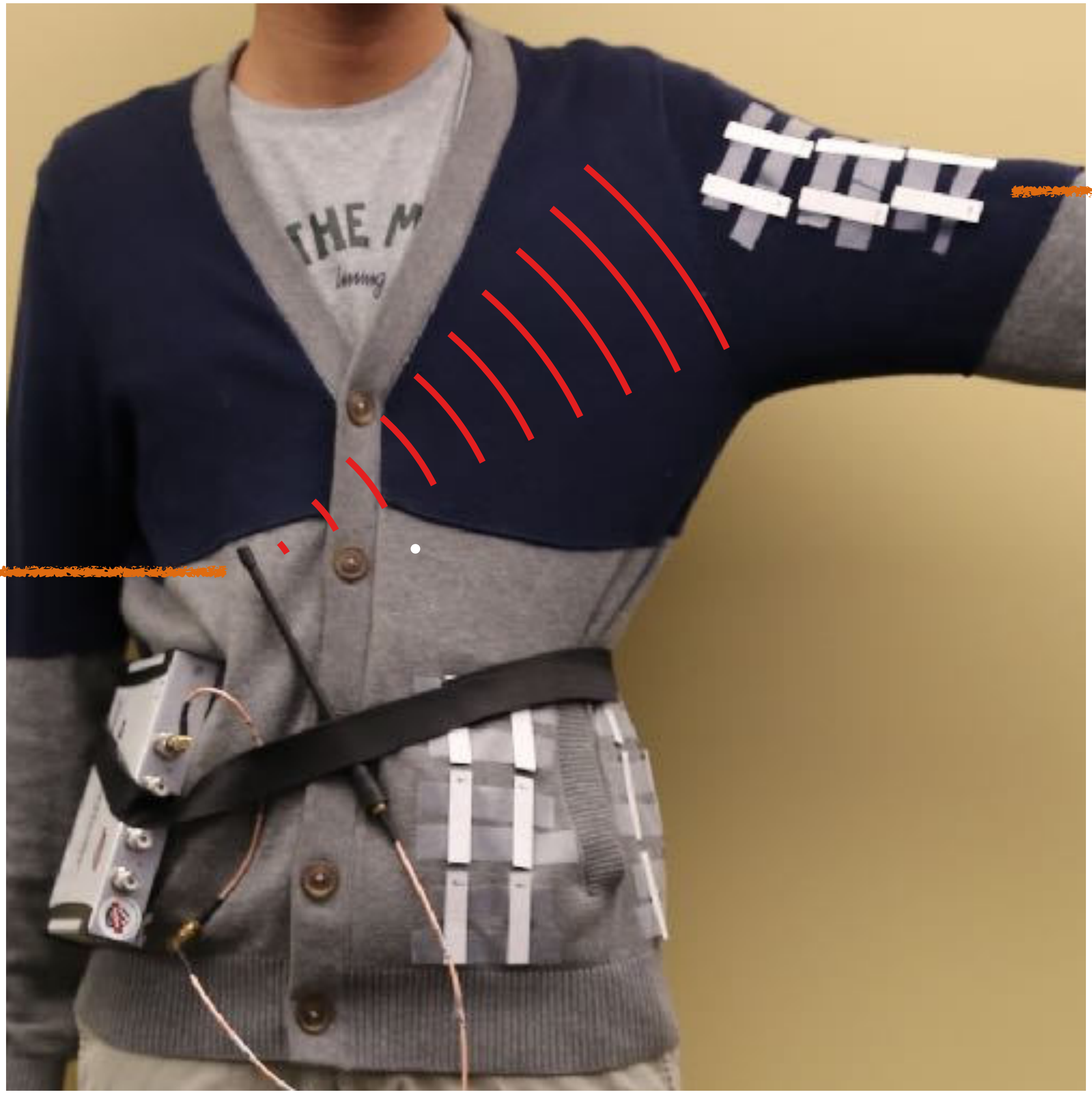
RFID Tags

RFID Antenna

RFID Reader

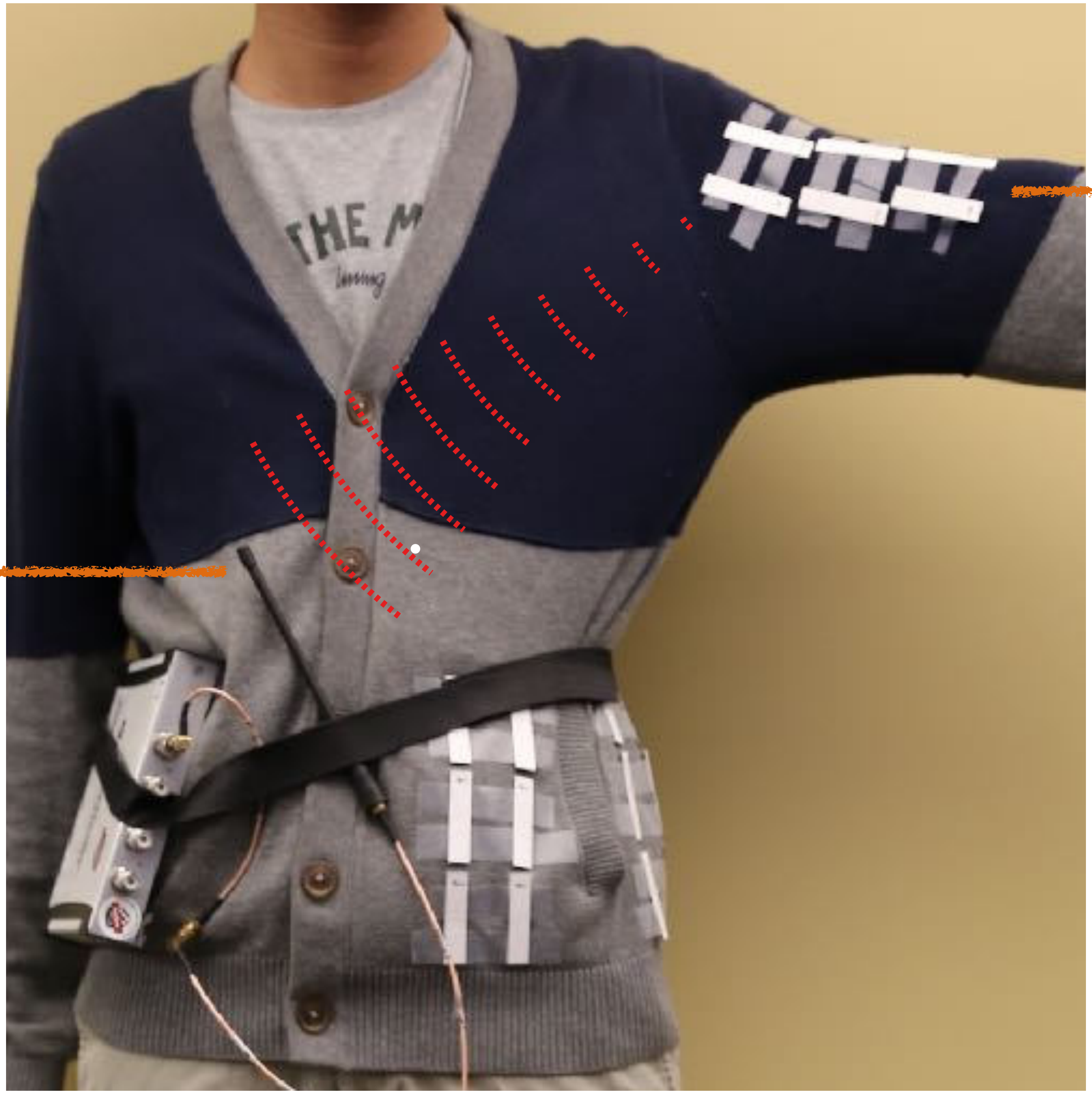
RFID Backscatter Communication

RFID Tags
(Reflector)



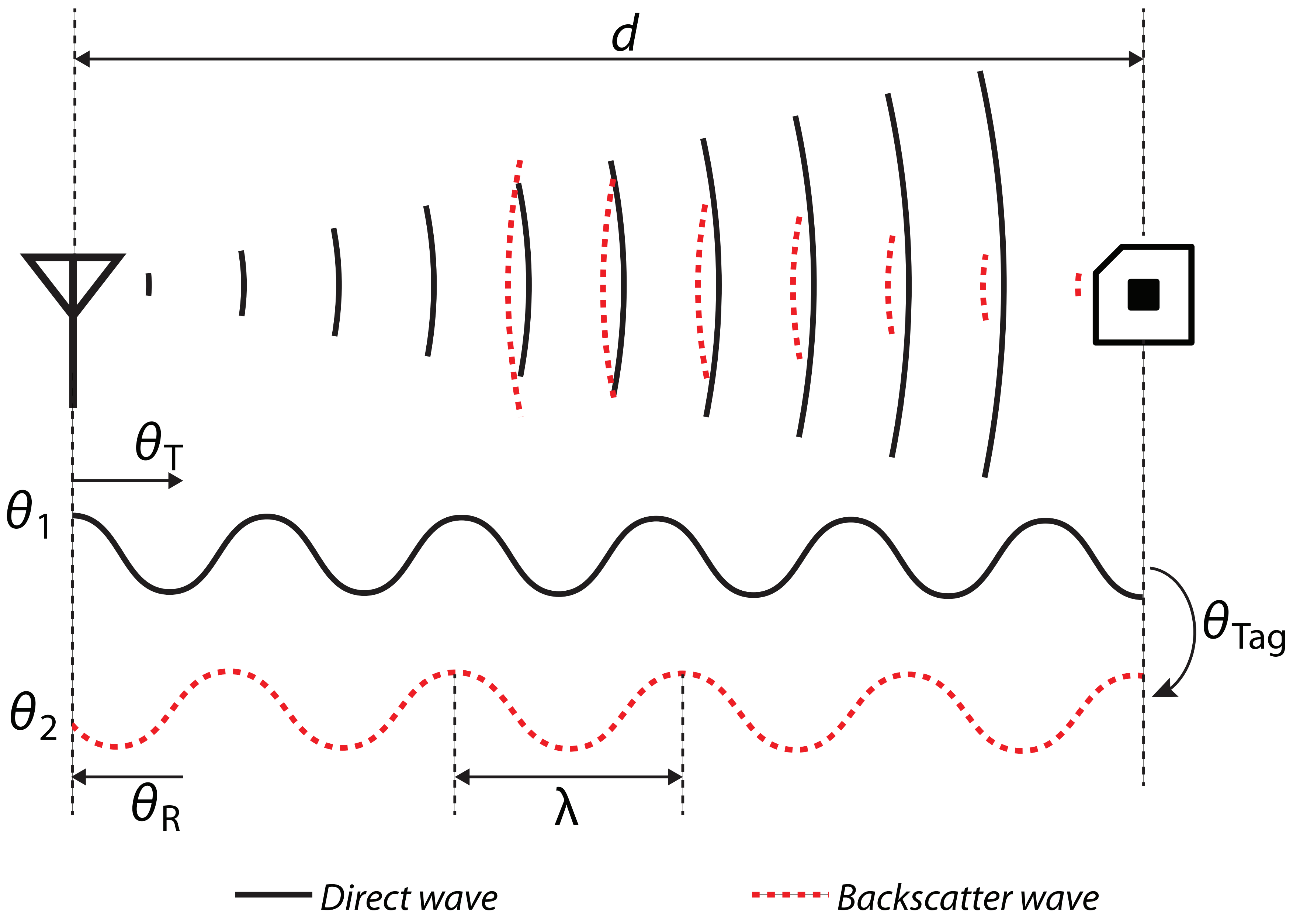
RFID Antenna
(Transmitter)

RFID Backscatter Communication



RFID Tags
(Reflector)

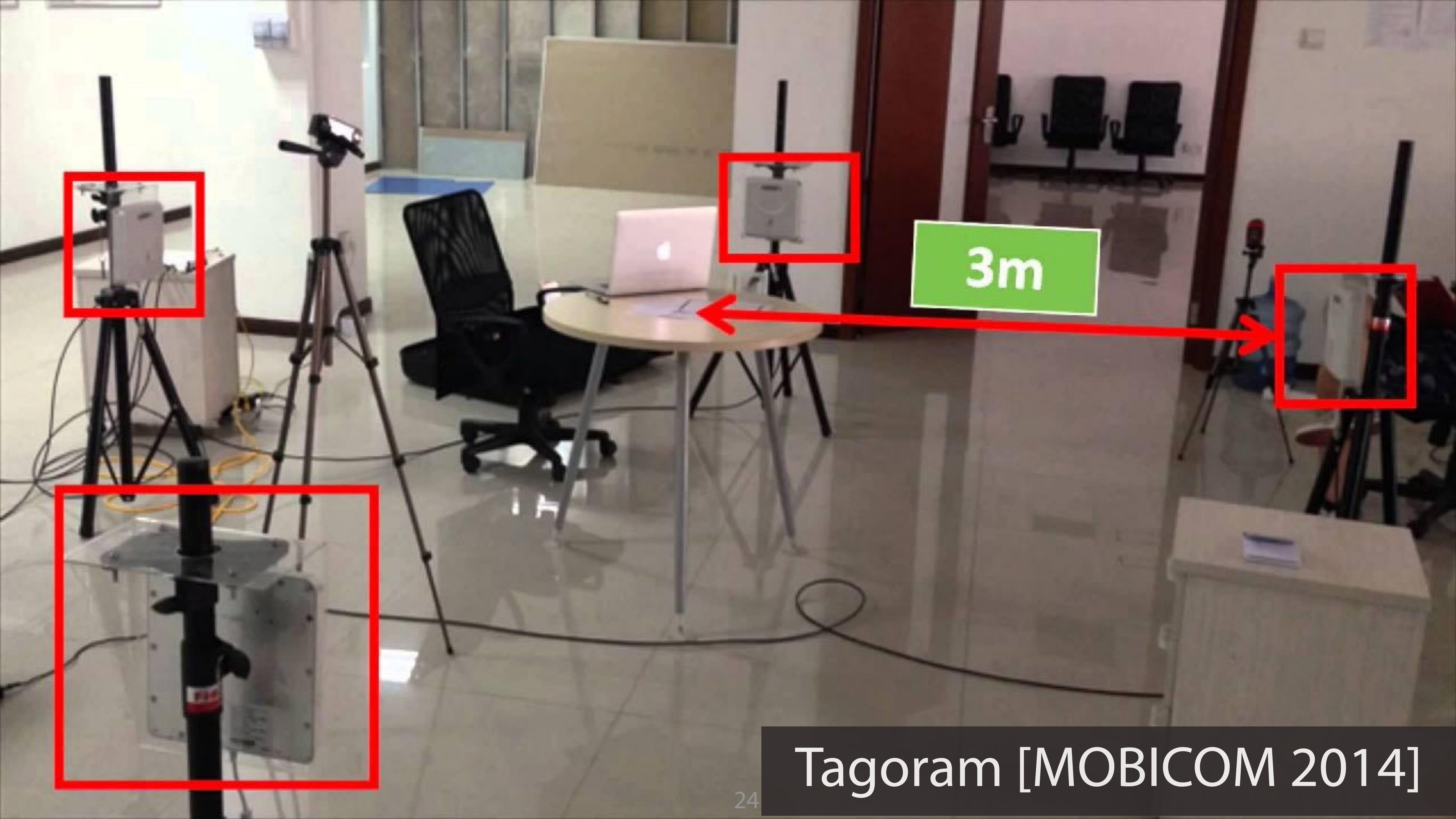
RFID Antenna
(Transmitter)



Phase Ranging resolution:

LESS THAN 0.1 mm

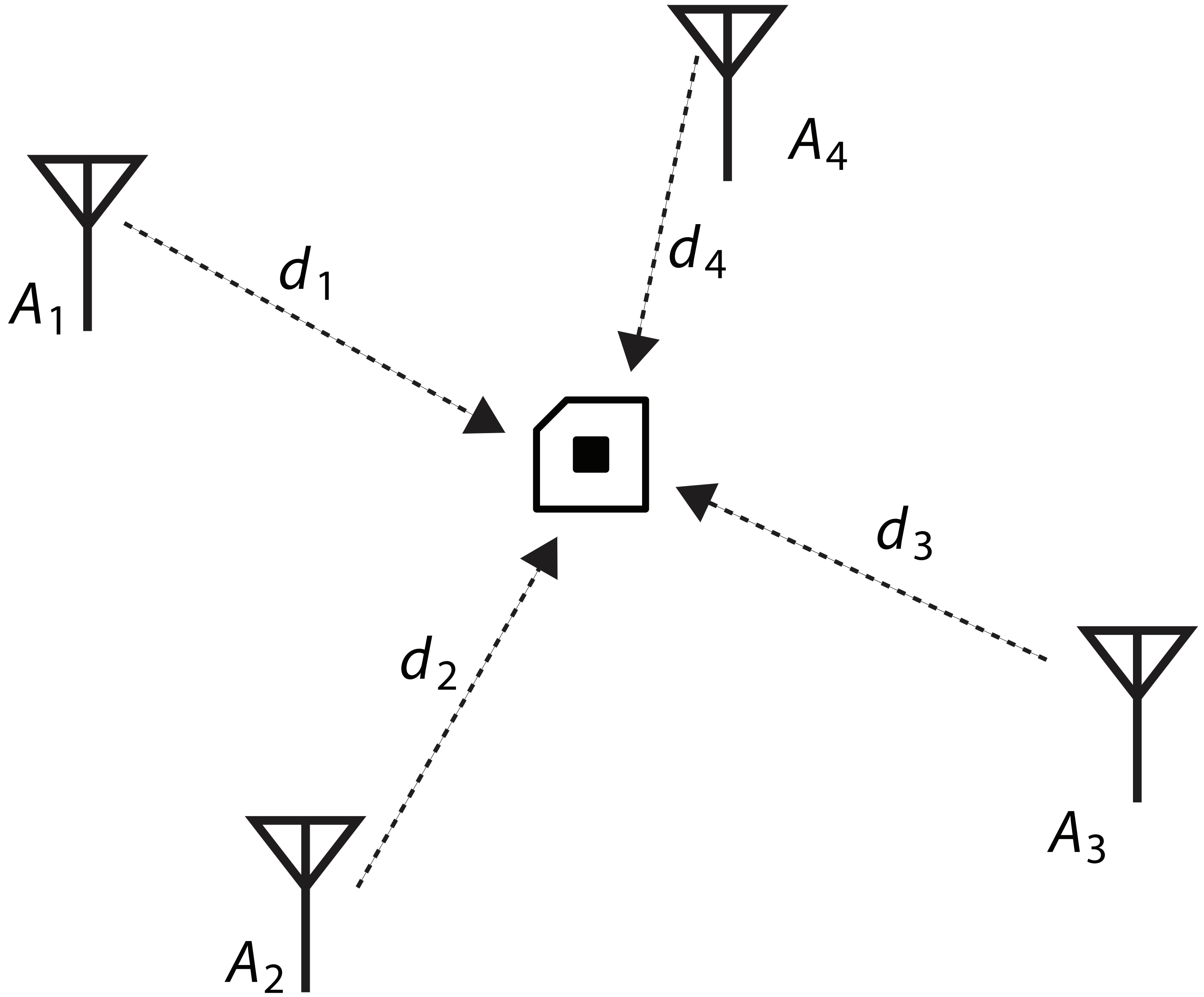
Phase in Backscatter Communication


3m
Tagoram [MOBICOM 2014]

Stationary RFID Sensing

Static multiple antennas at known positions

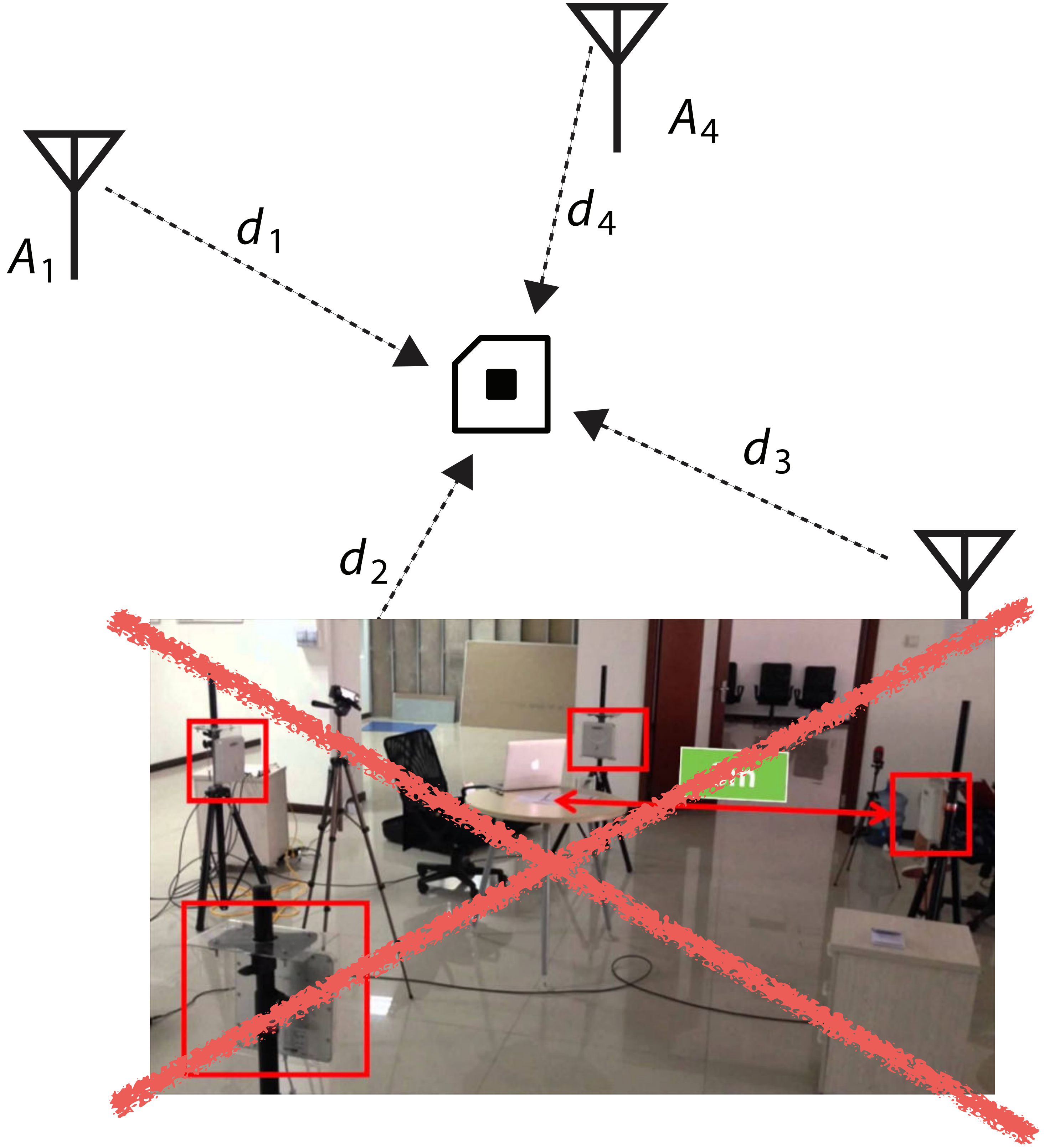
Use triangulation to calculate the tag position

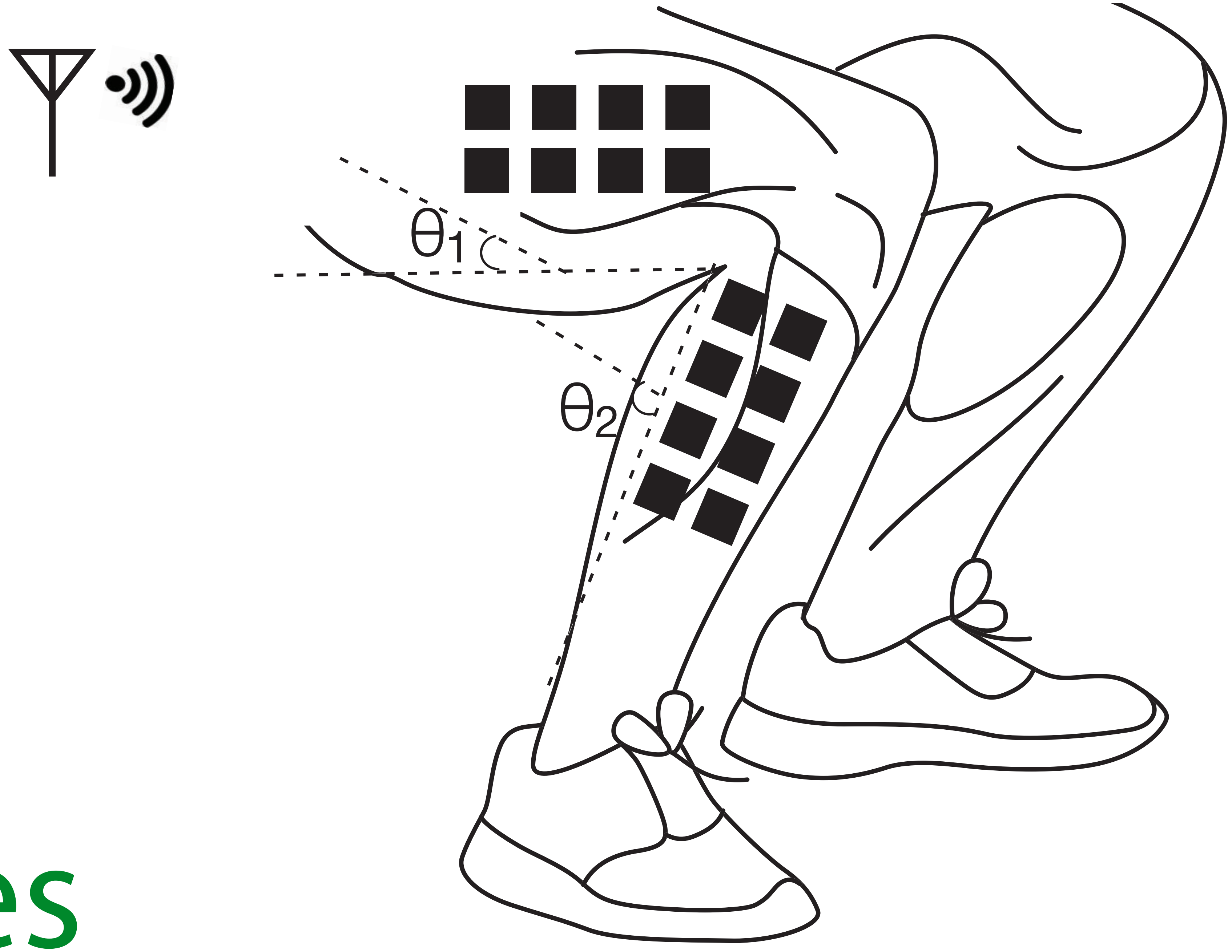


Mobile/Wearable
~~Stationary~~ RFID Sensing

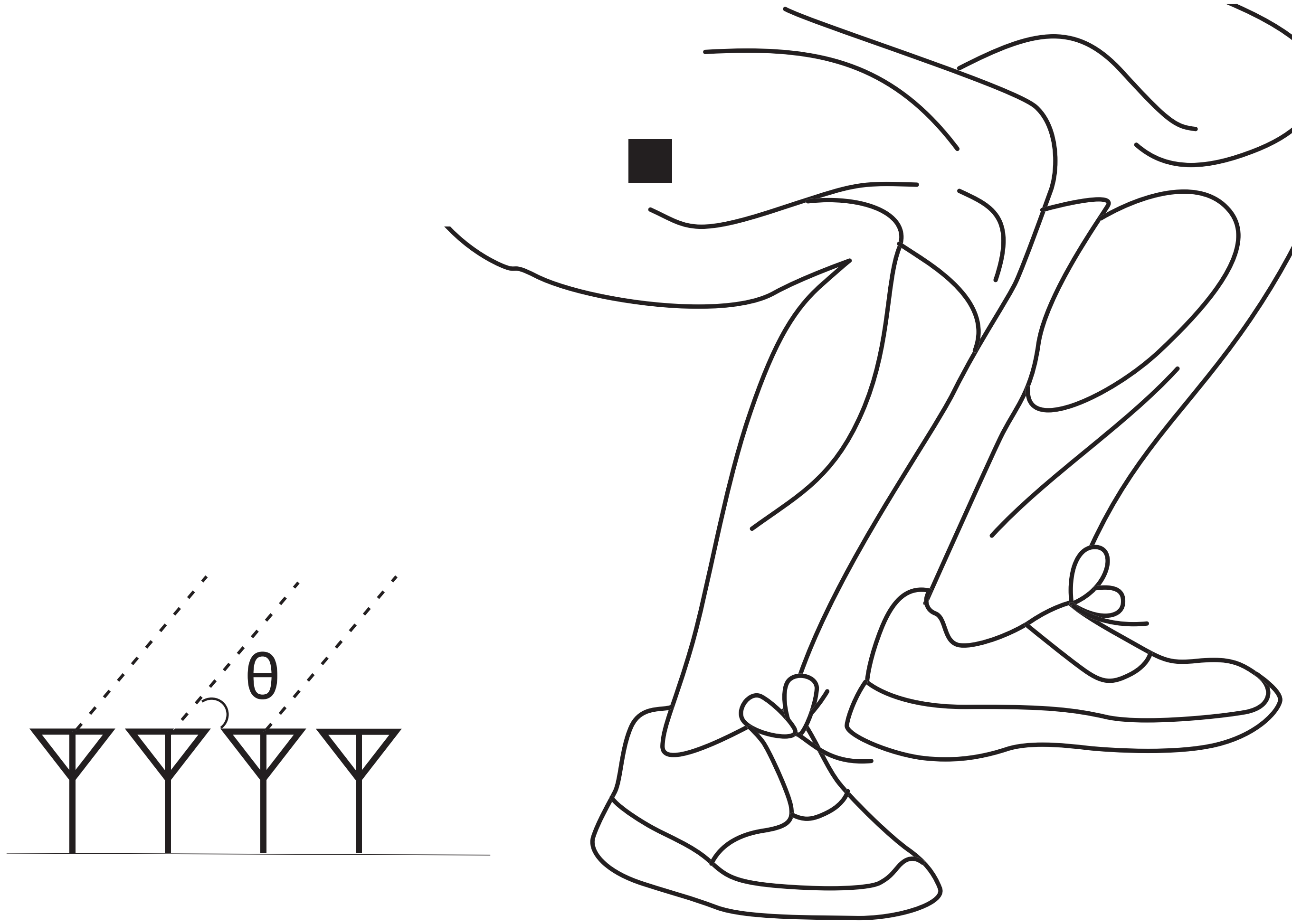
~~Static multiple~~ antennas at ~~known~~ positions

Use ~~triangulation~~ to calculate the tag position

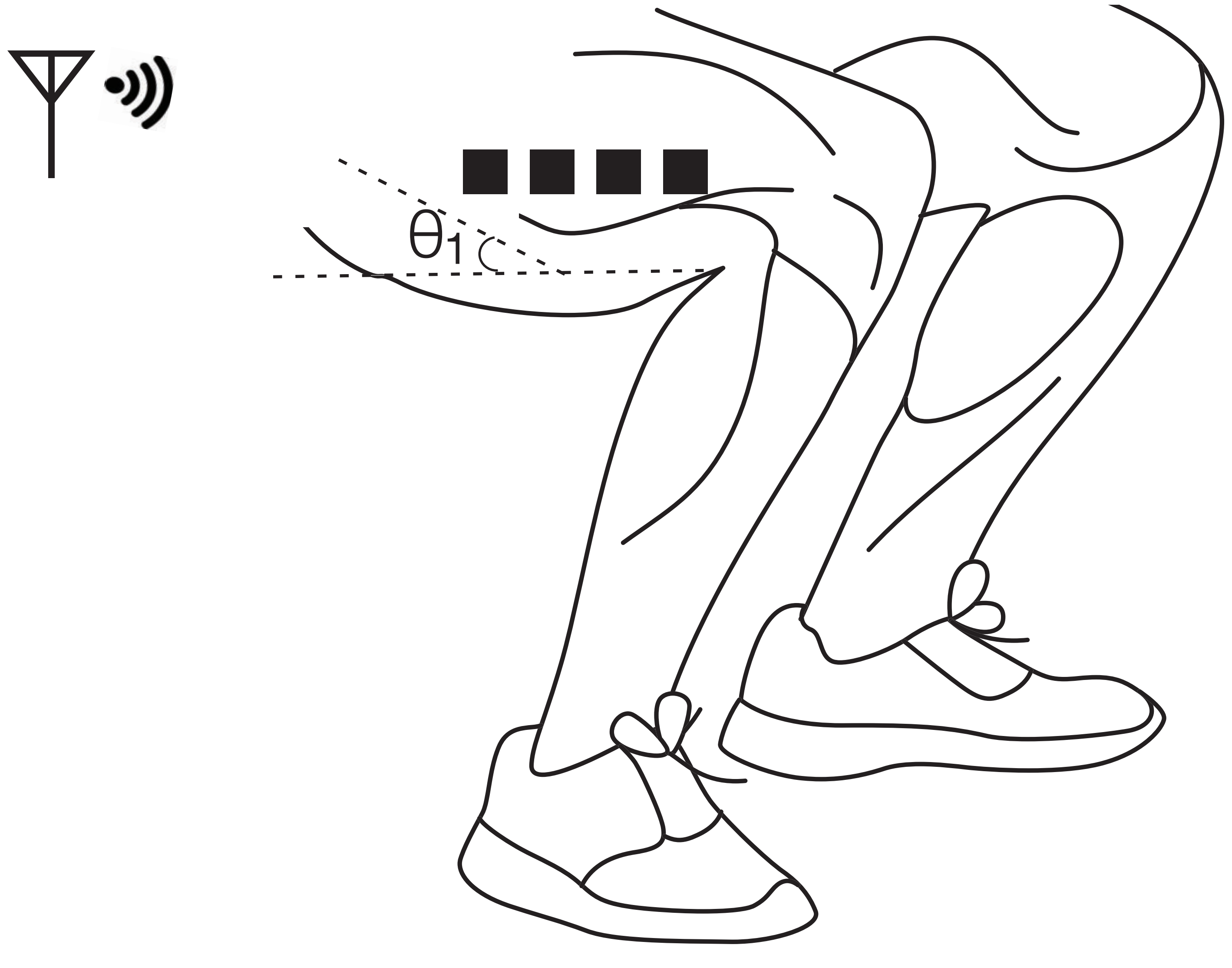




RF-Wear
Key Primitives

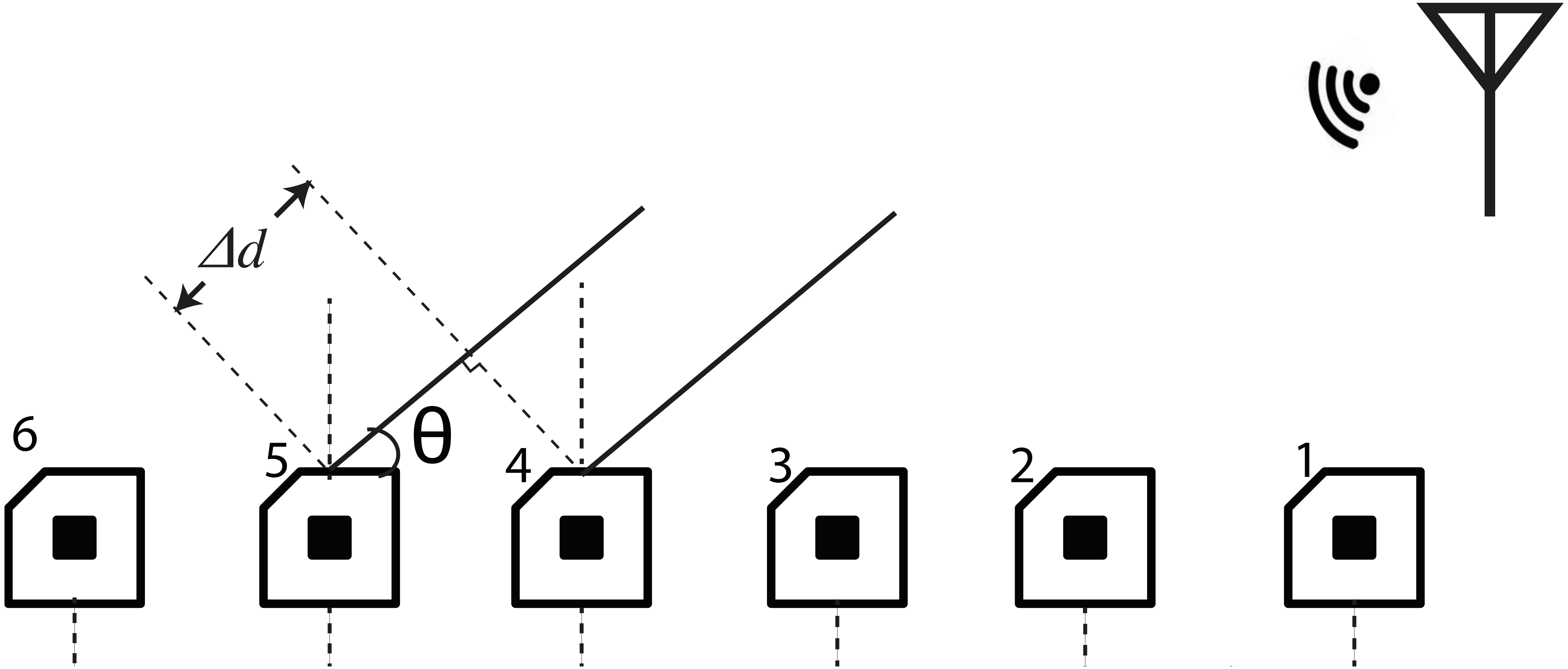


past work

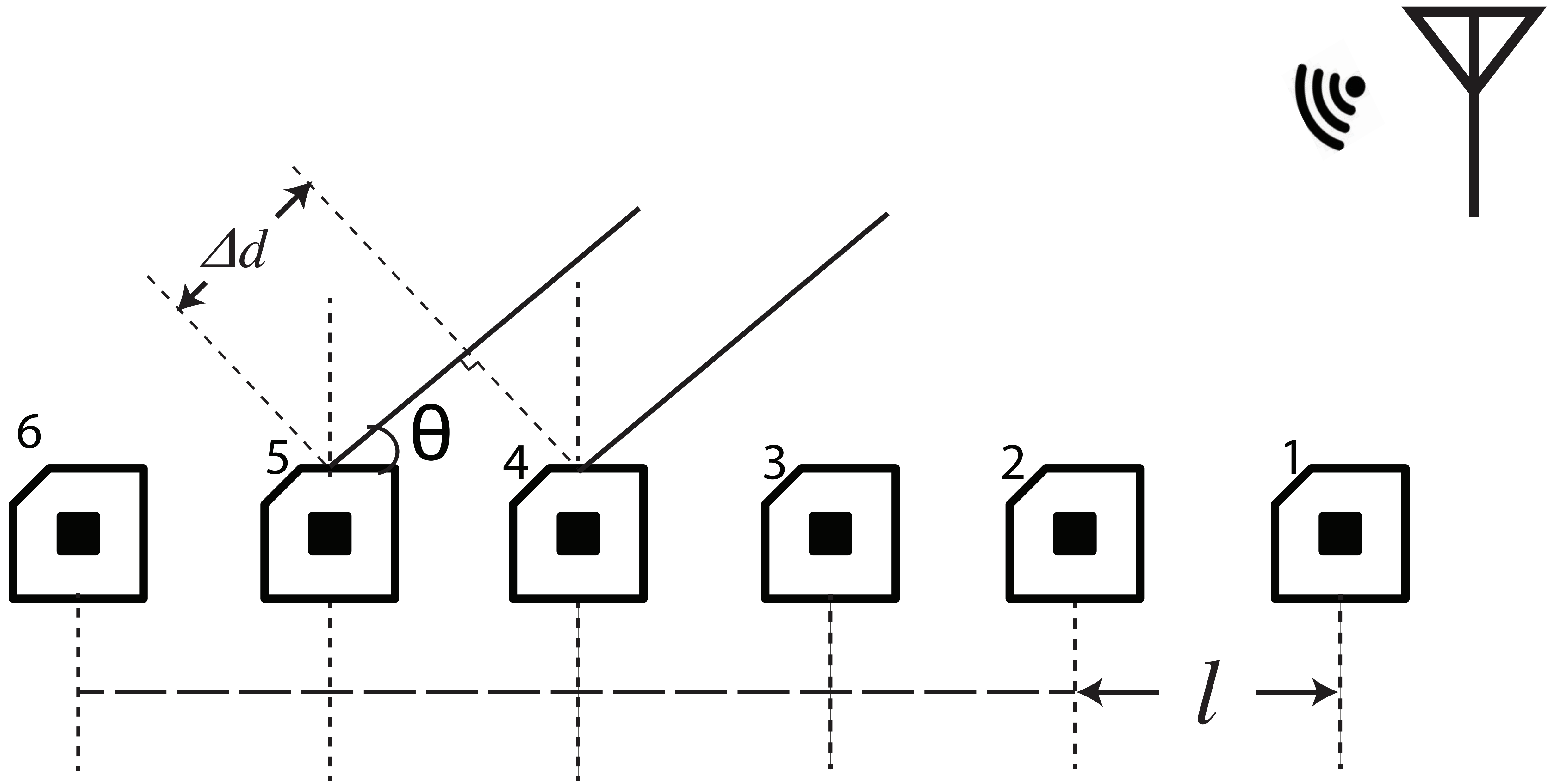


RF-Wear

reversing the tag-antenna relationship



measure the radio signal
time-of-arrival delay

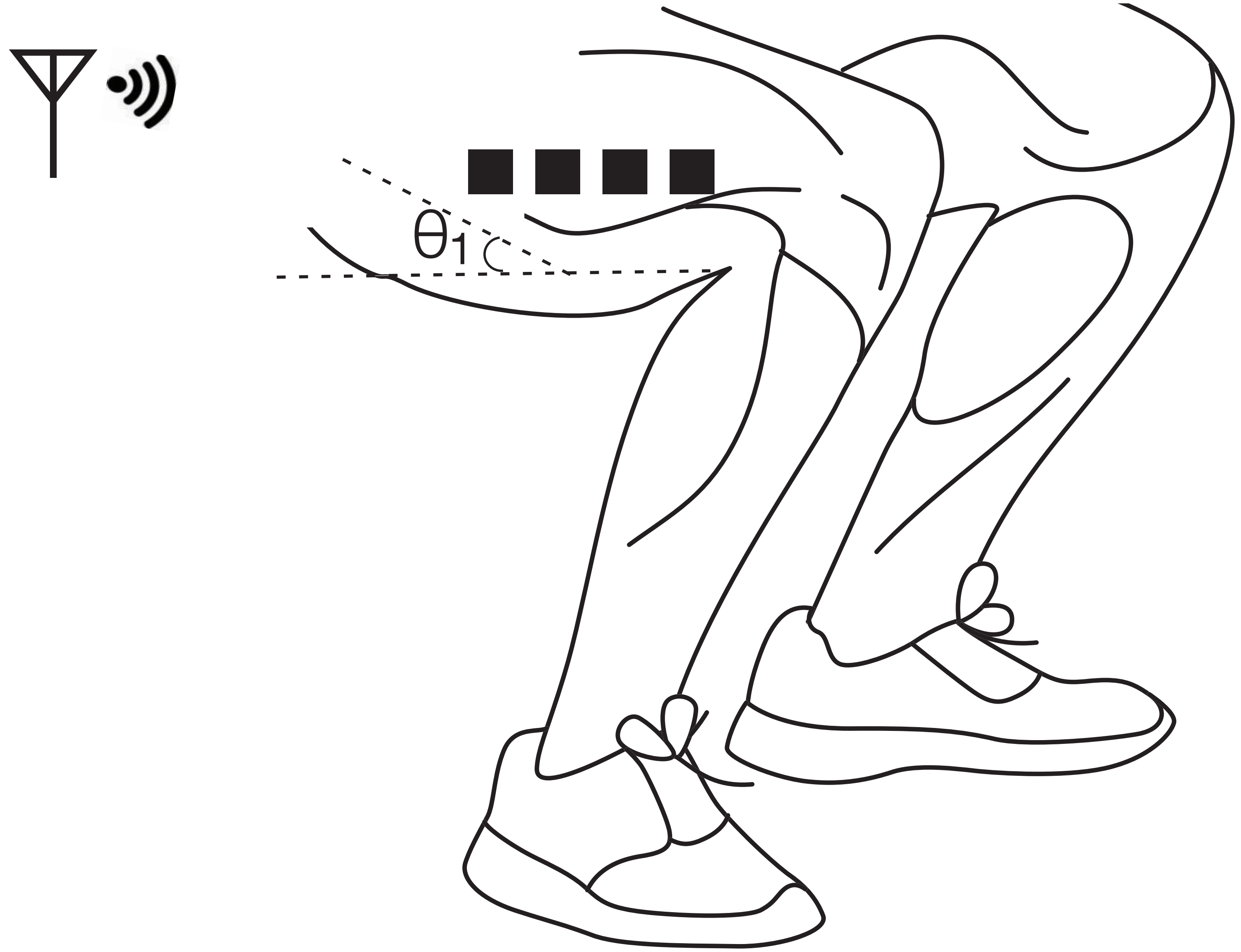


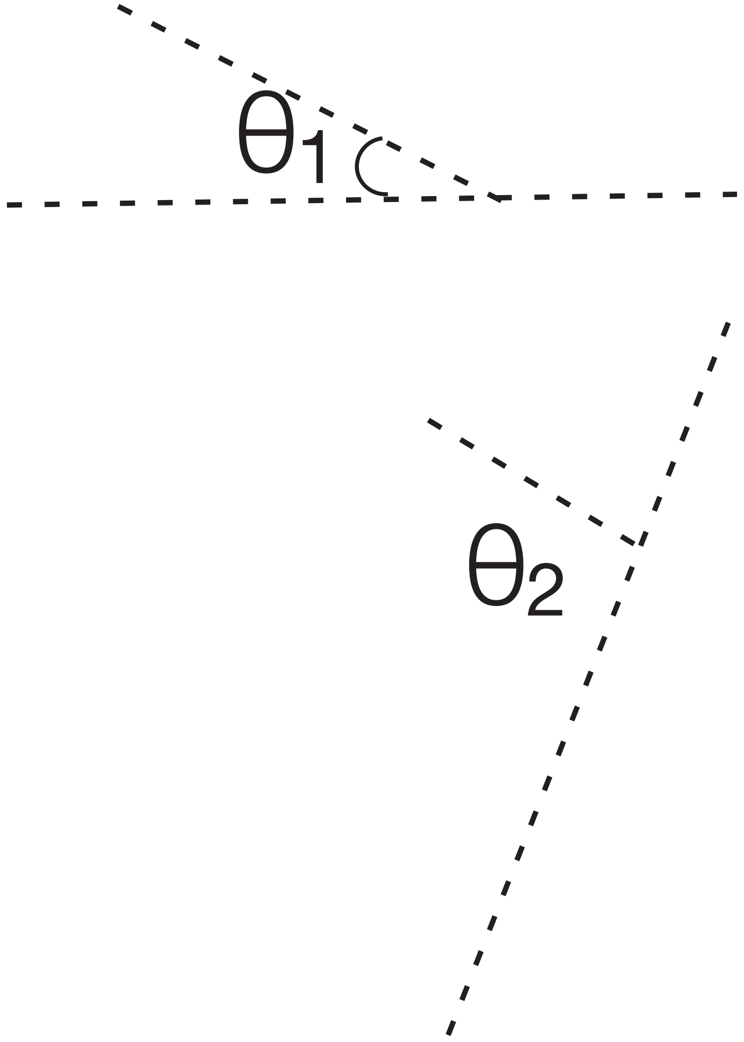
$$\cos\theta = \frac{\Delta d}{l}$$

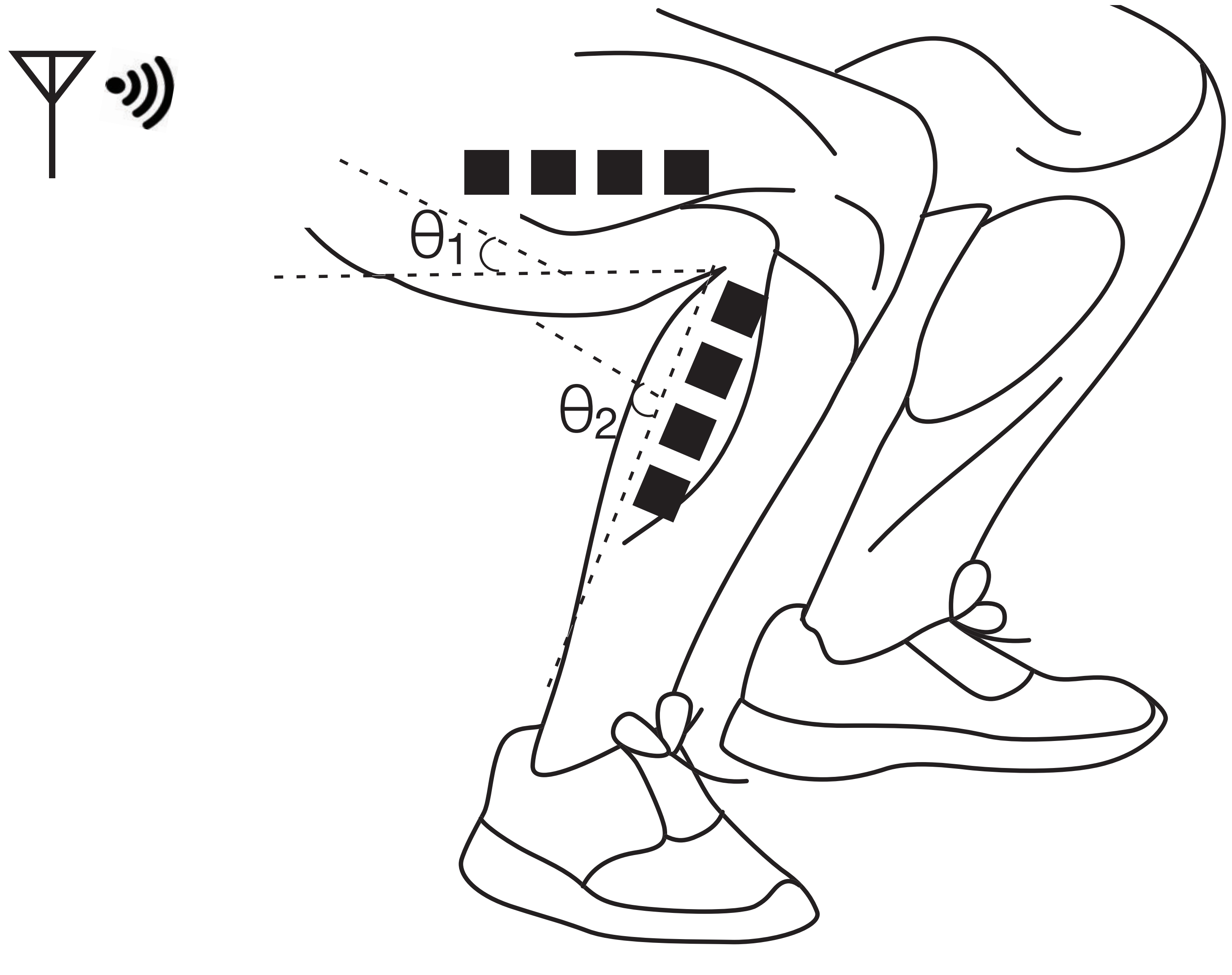
the tag placement *l* is known

the antenna is in the pocket

the position may change
when the user moves







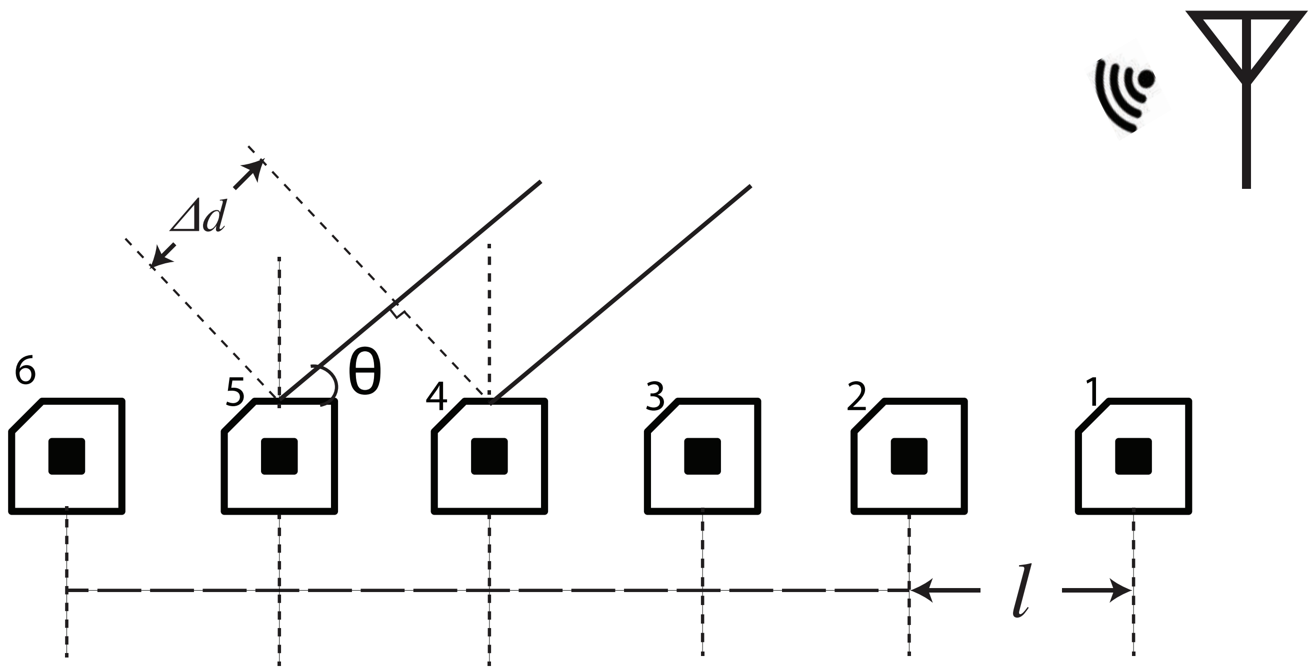
knee joint angle = $\theta_2 - \theta_1$

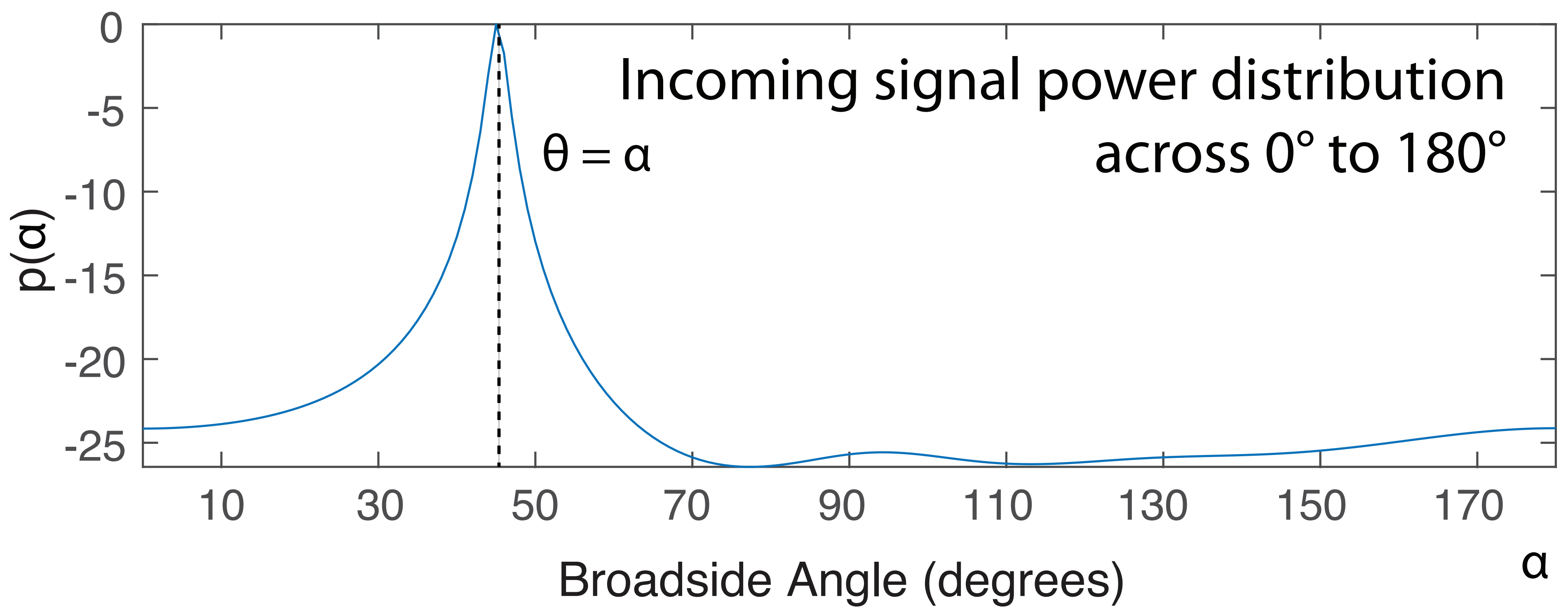
ideally…

in reality…

multipath

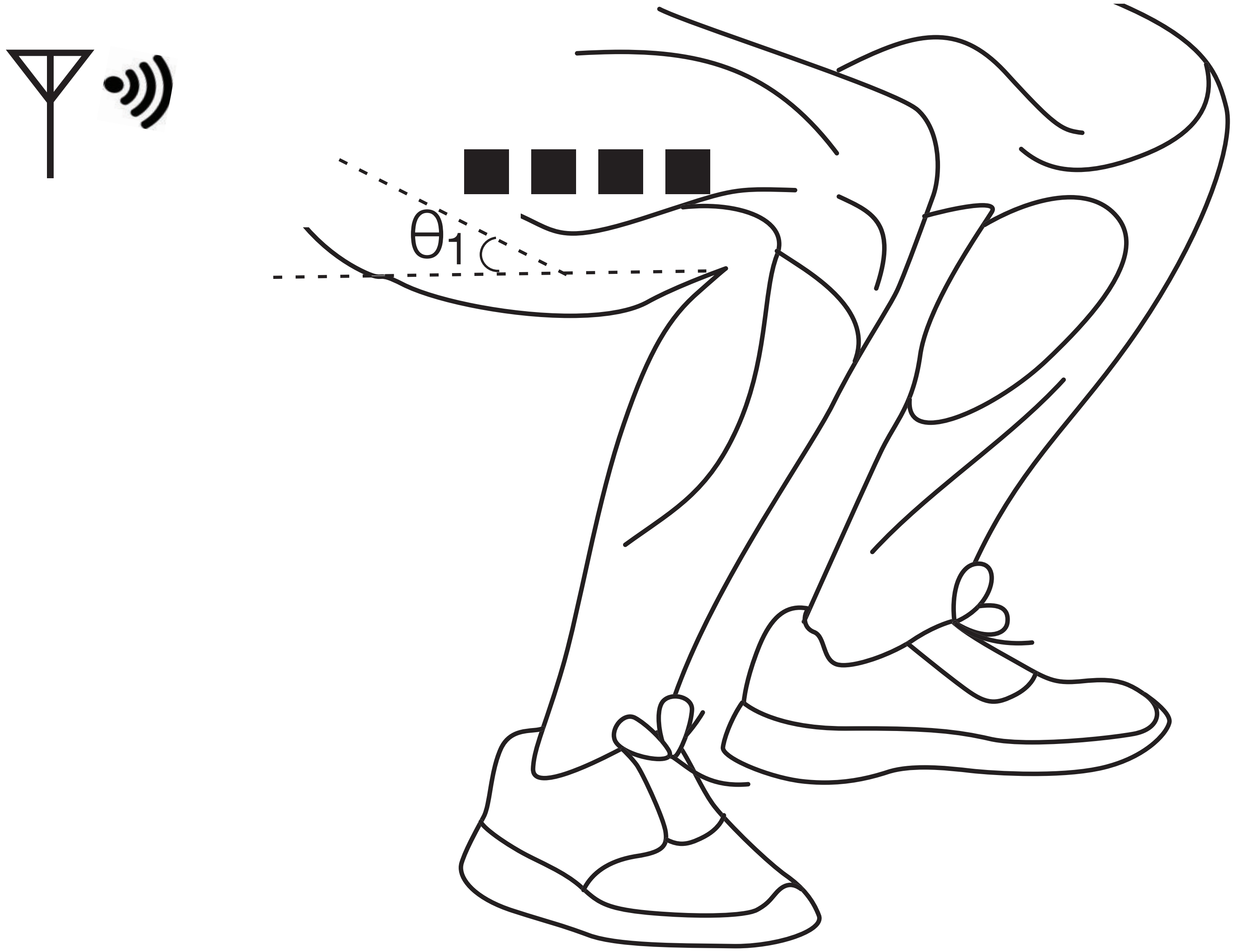
Eigenspace method (MUSIC algorithm)

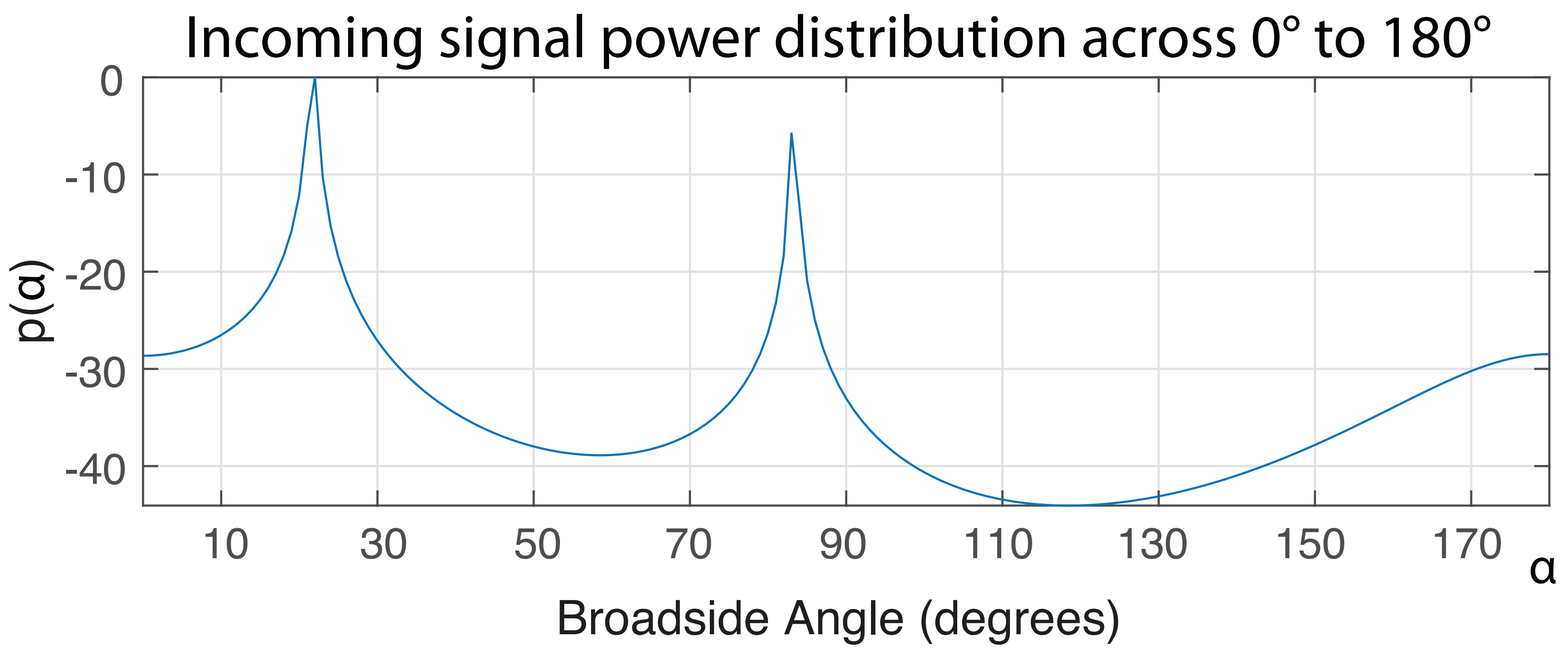


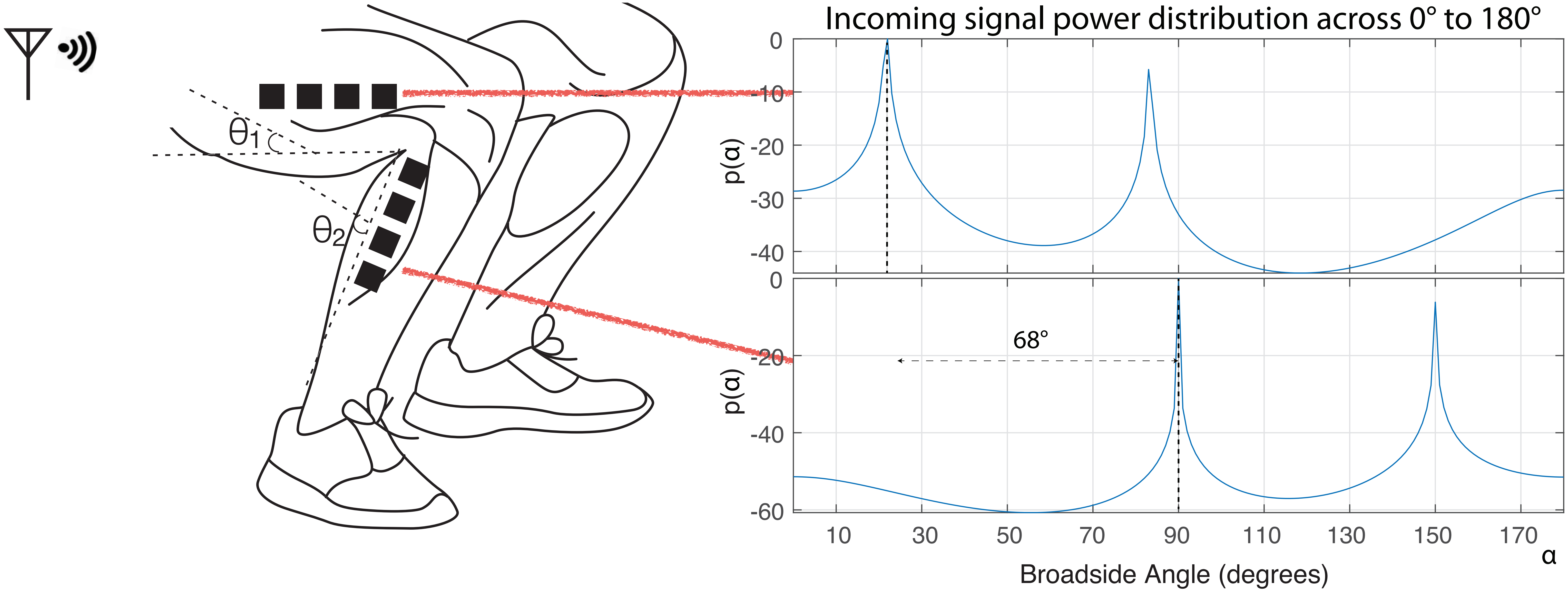


$$P(\alpha) = \frac{1}{|a(\alpha)E_N E_N^* a(\alpha)^*|}, \text{where: } a(\alpha) = [e^{4\pi j r_i cos(\alpha)/\lambda}]_{i=1,\ldots,N}$$

Real-world Spectrum





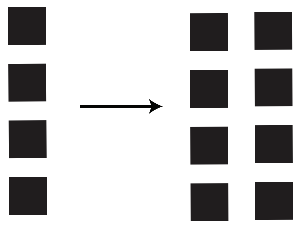


measure the offset of two spectrum to counter multipath signals

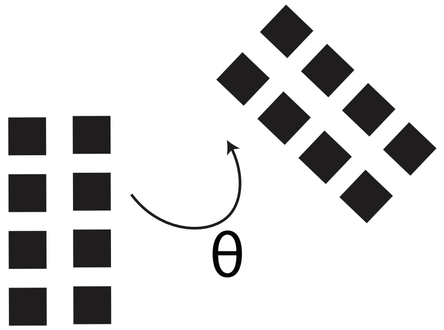
RF-Wear on Body

challenges on-body

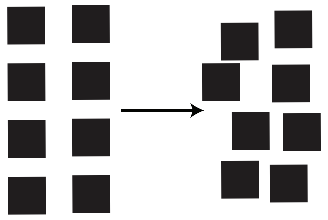
1 2D sensing primitives to 3D space



2 Two Degree of Freedom Joints

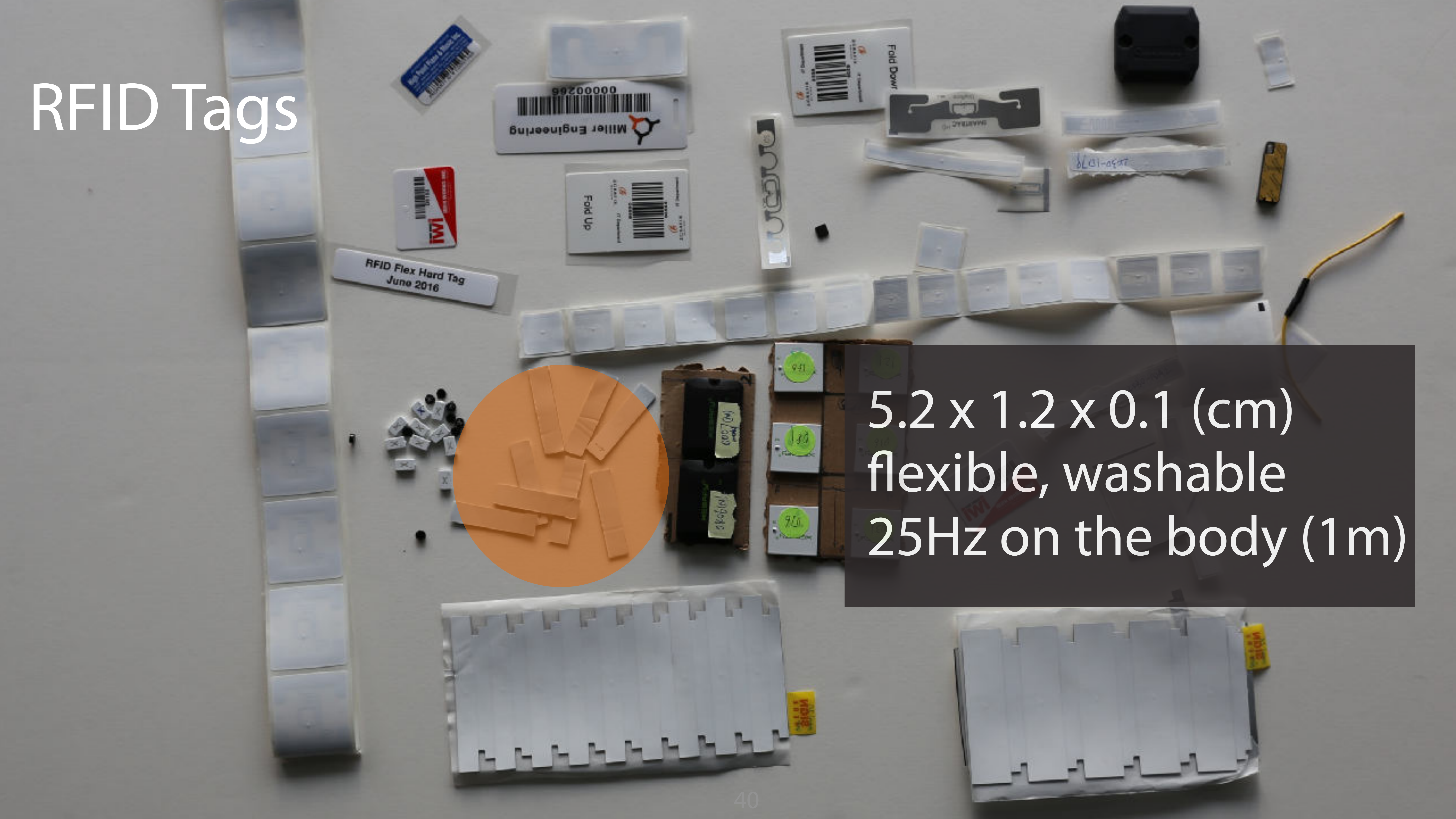


3 Fabric flexibility



implementation

RFID tags, RFID readers, Software


RFID Tags
5.2 x 1.2 x 0.1 (cm)
flexible, washable
25Hz on the body (1m)
Miller Engineering
Fold Up
Fold Down
RFID Flex Hard Tag
June 2016

Software

implemented in Python

computation time: 0.03s => live demo (15 Hz)

raw signal rate at 20~60 Hz

continuous skeleton tracking

Context:

RapID [CHI'16] - 200 ms

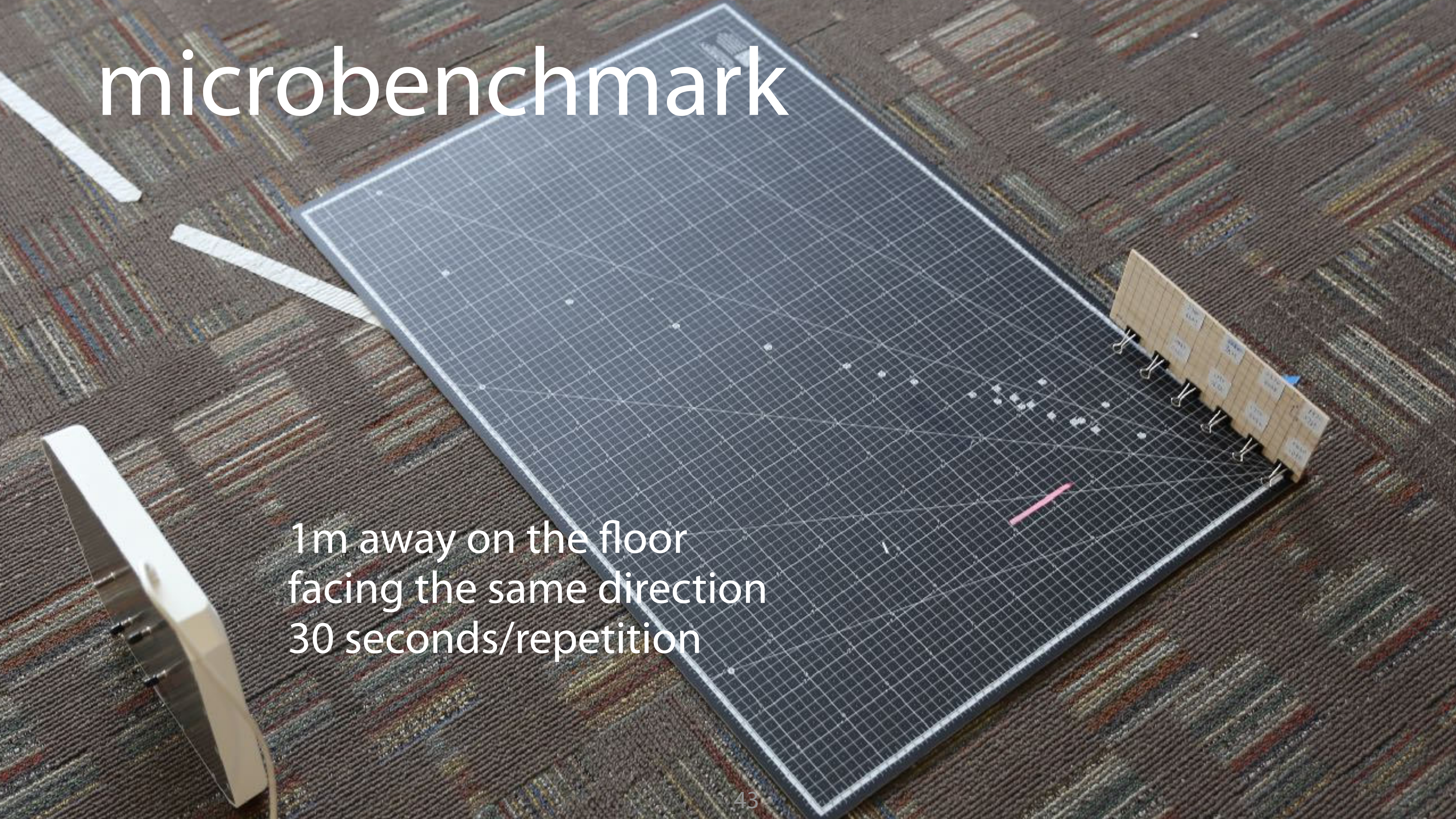
IDSense [CHI'15] - 2s

discrete gesture recognition

evaluation

1) Array geometry
2) Fabric flexibility
3) Motion capture experiment

microbenchmark



1m away on the floor
facing the same direction
30 seconds/repetition

6 tag array dimensions
[2x3; 2x4; 2x5; 3x3; 4x4; 5x5]

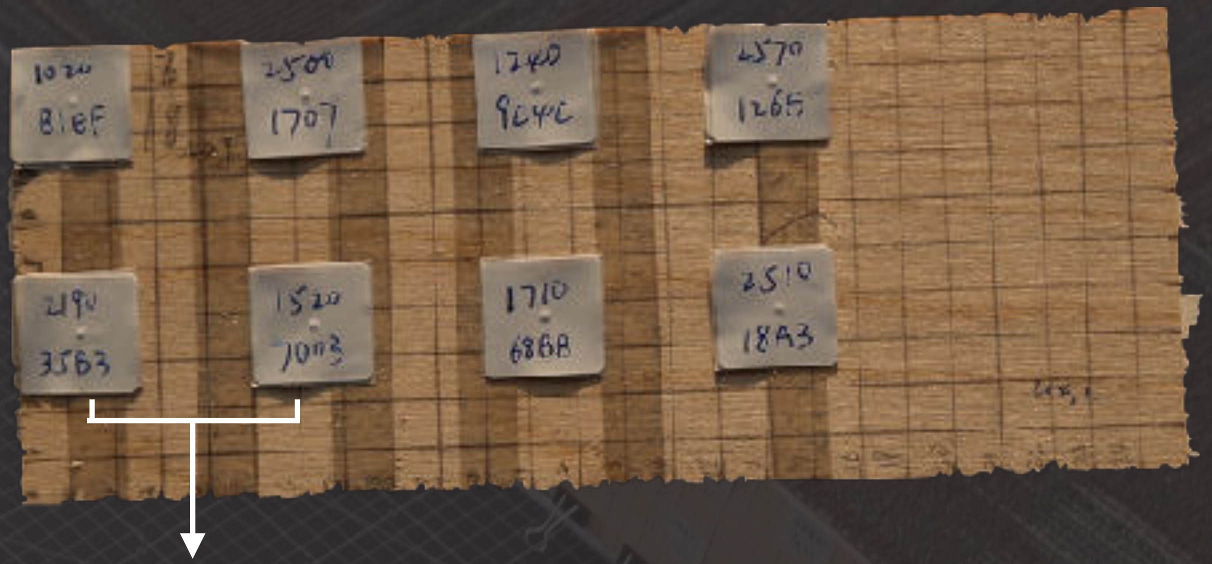
X 3 aperture
[3cm, 4cm, 5cm]

X 6 relative angles
[30°, 60°, 90°, 120°, 150°, 180°]

X 3 repetitions

= **324 experiments**

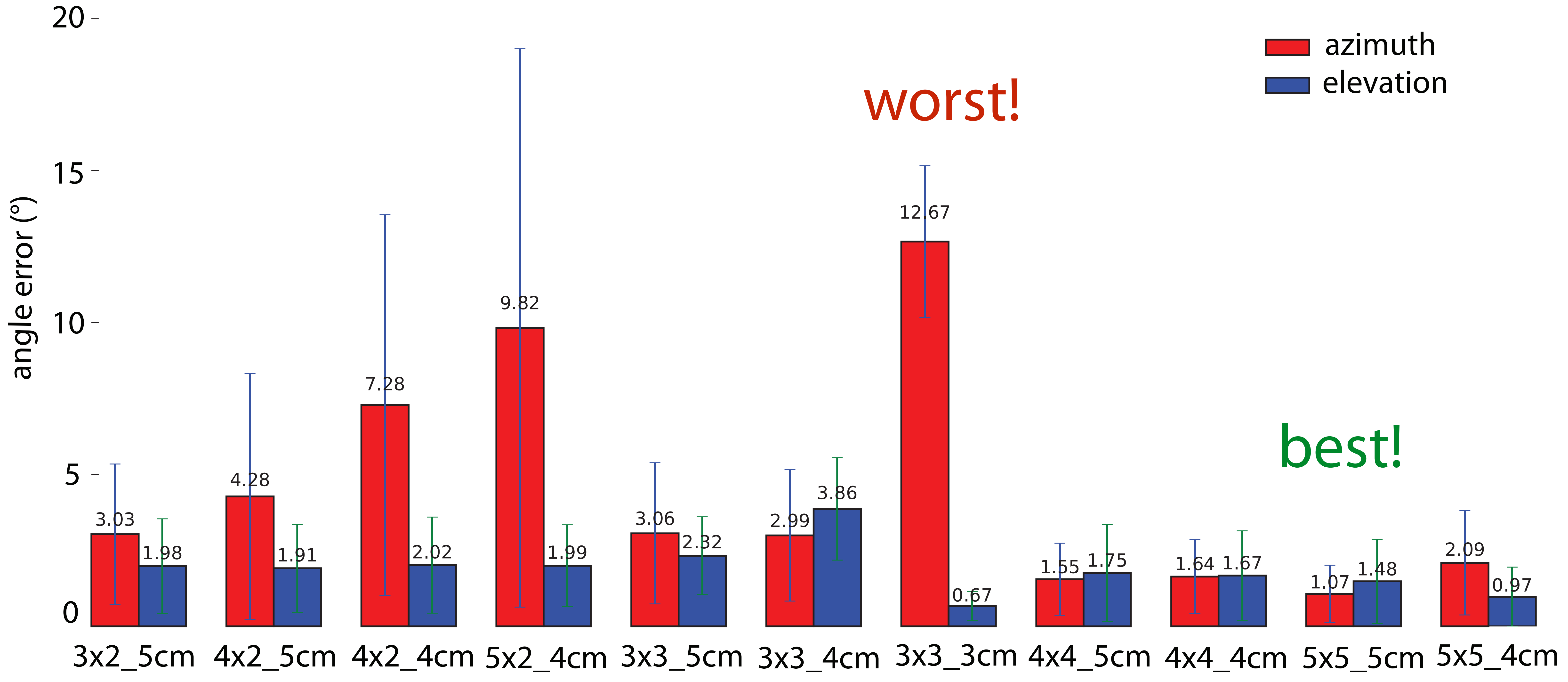
example: 2x4



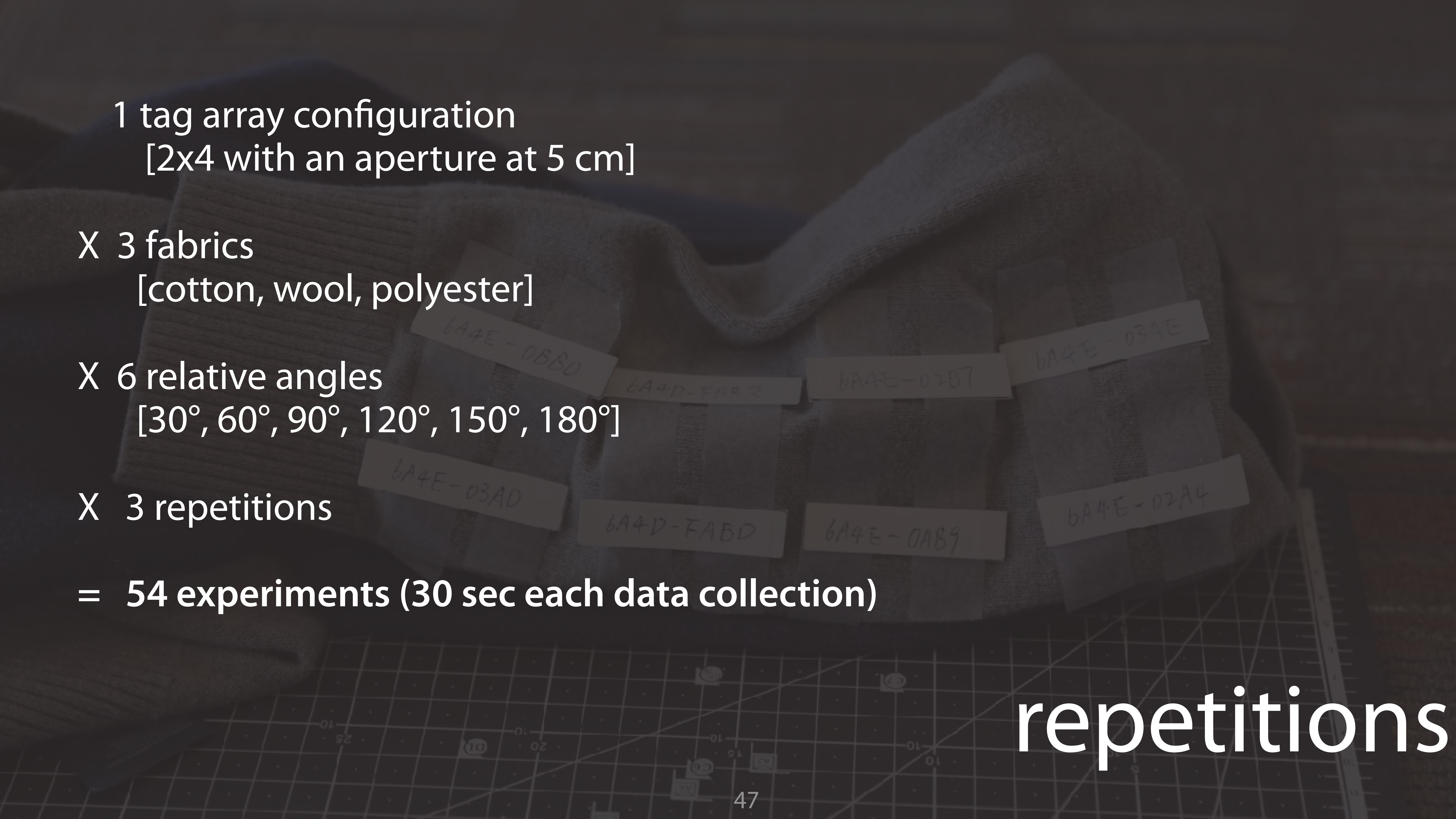
aperture: 5cm

repetitions

microbenchmark accuracy



fabric flexibility test



1 tag array configuration
[2x4 with an aperture at 5 cm]

X 3 fabrics
[cotton, wool, polyester]

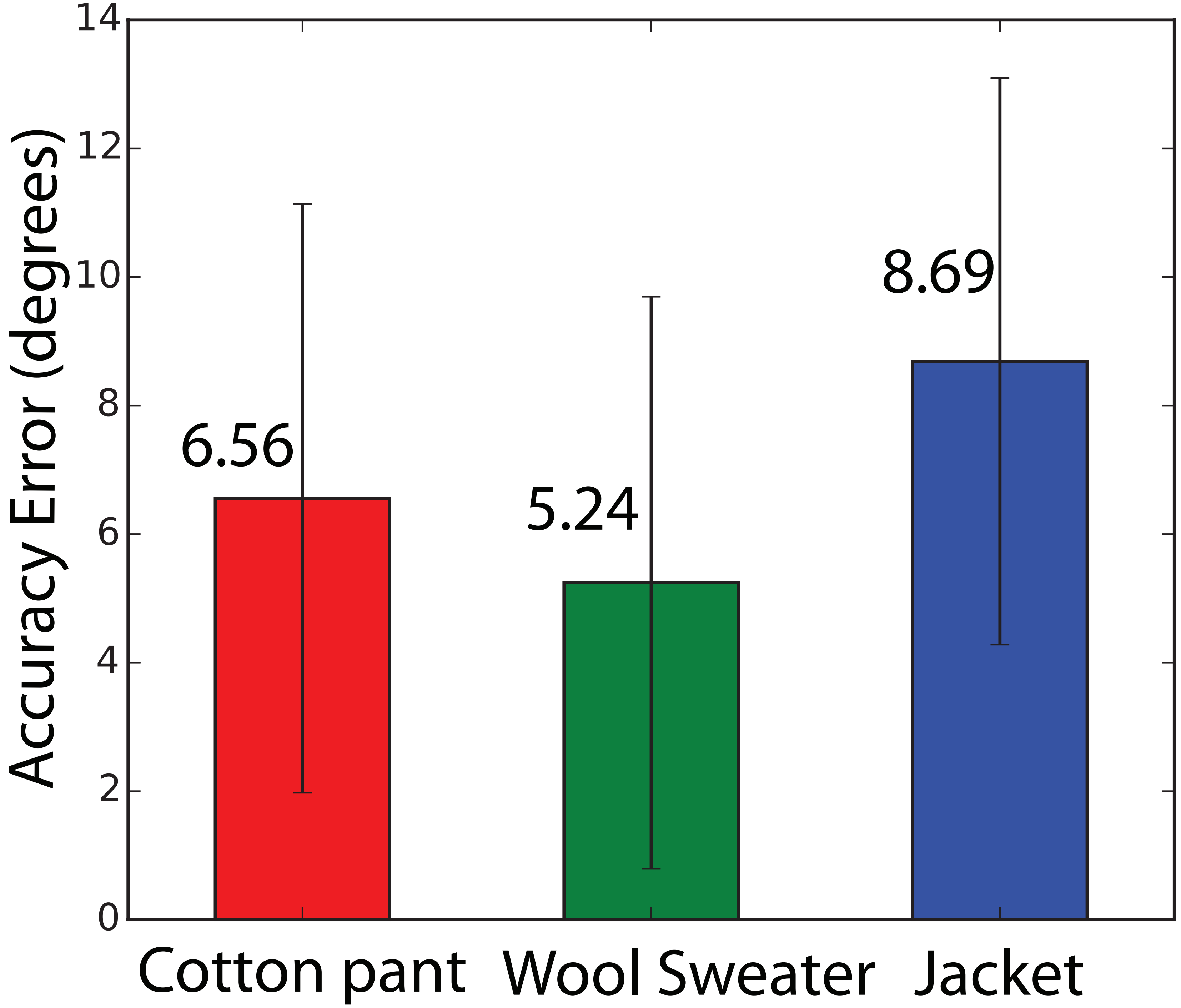
X 6 relative angles
[30°, 60°, 90°, 120°, 150°, 180°]

X 3 repetitions

= **54 experiments (30 sec each data collection)**

repetitions

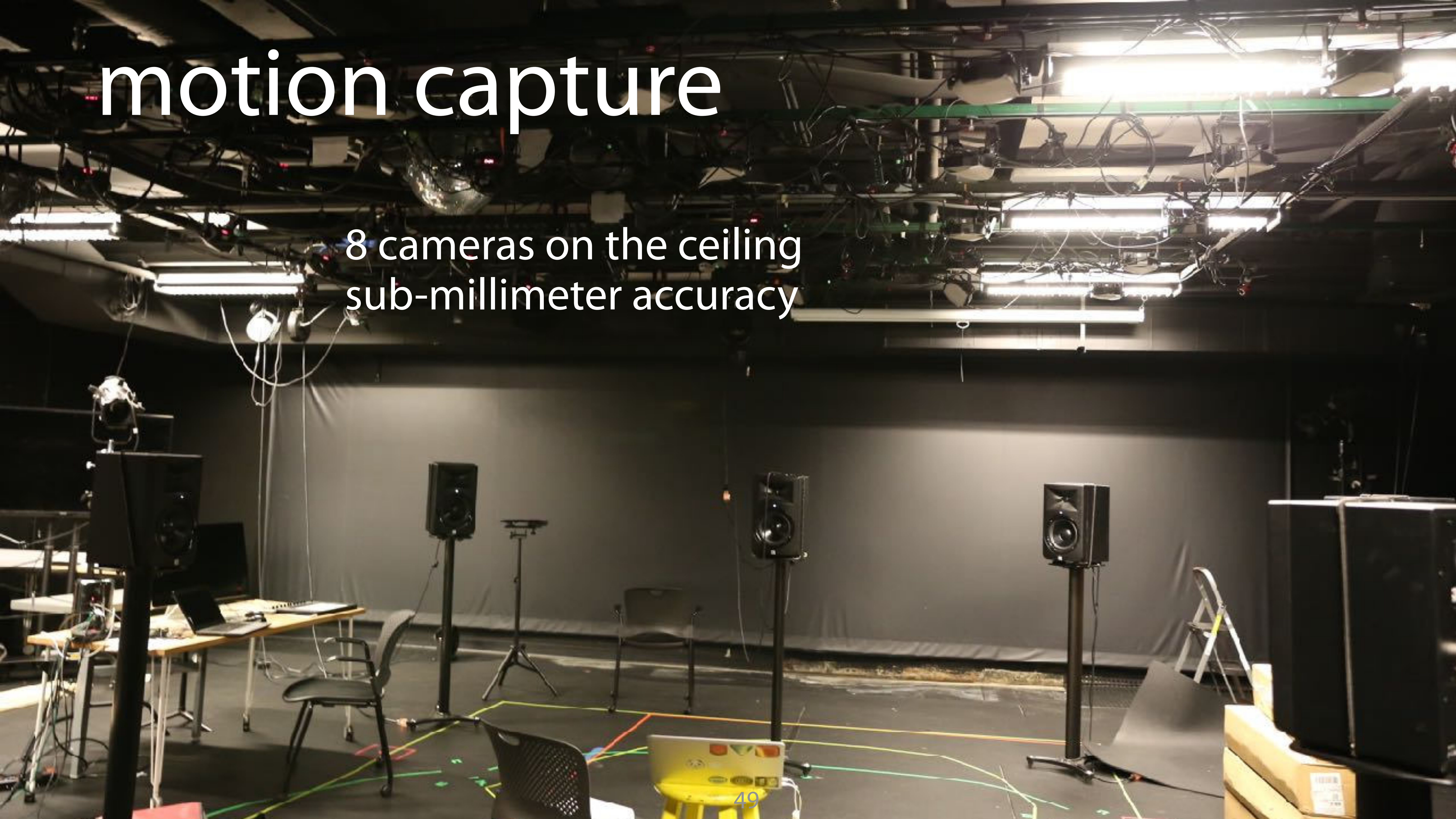
fabric flexibility test

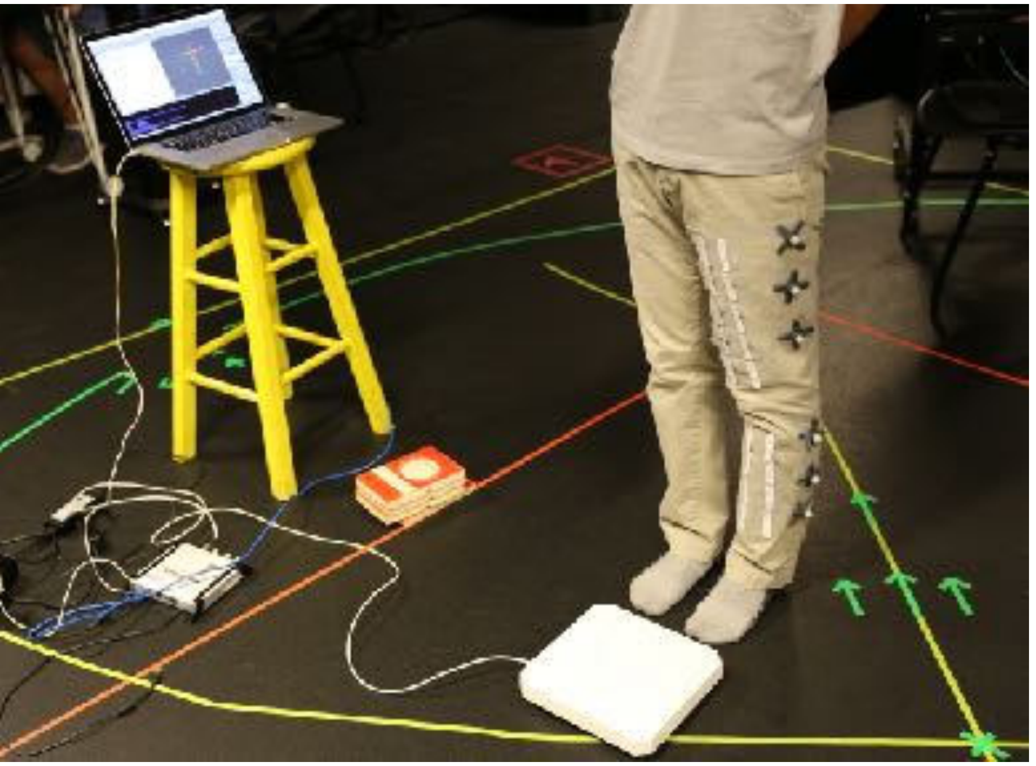


context:
cardboard: 4°

motion capture

8 cameras on the ceiling
sub-millimeter accuracy





knee

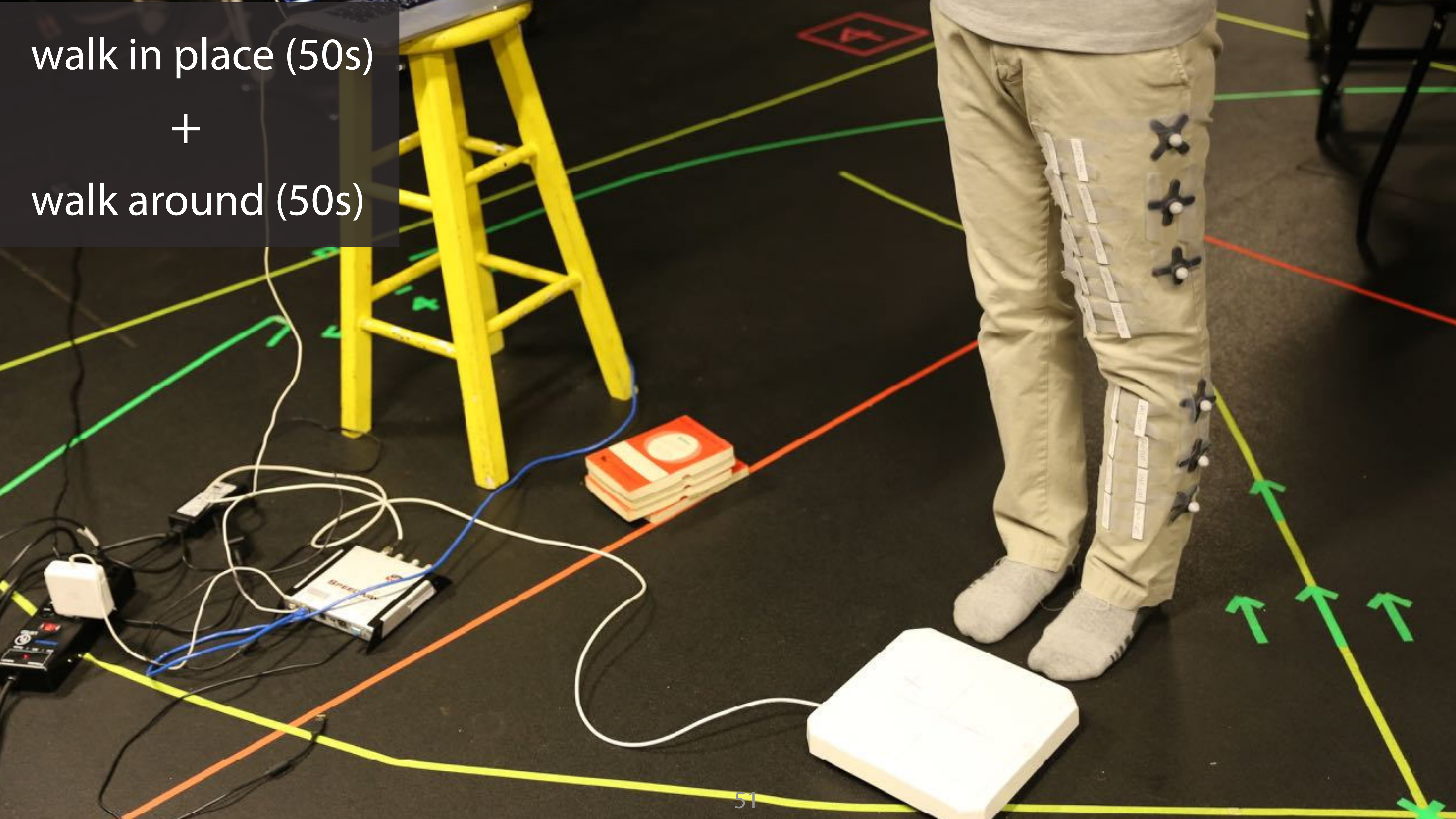
elbow

shoulder

walk in place (50s)

+

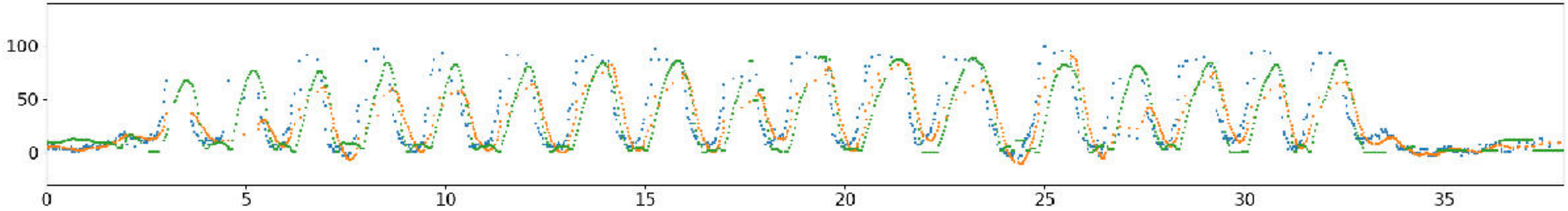
walk around (50s)



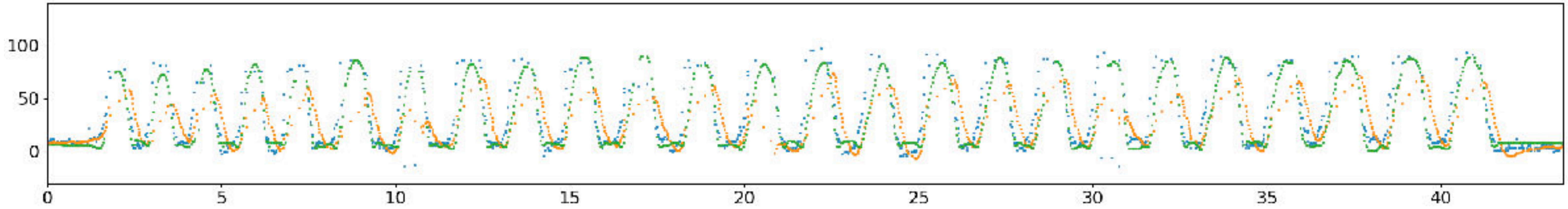
knee joint angle trace

knee joint angle (°)

Walk in-place



Walk around

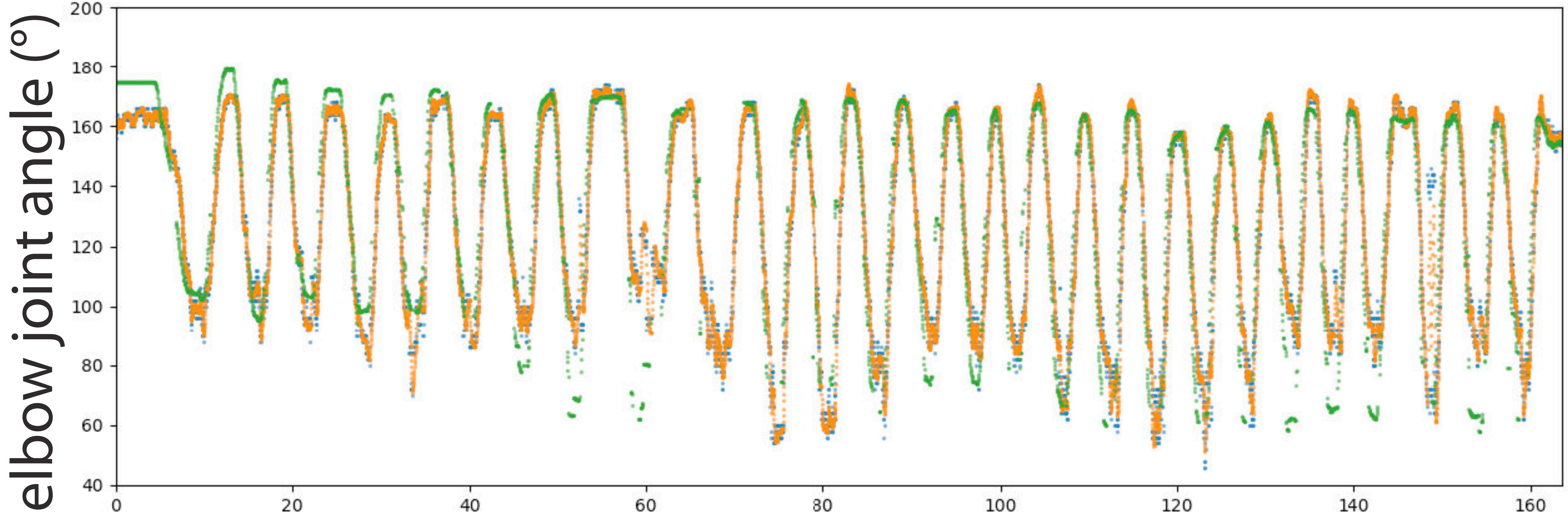


time (sec)

RF-Wear (Raw) RF-Wear (KF) GroundTruth


hand movement
(160 sec)

elbow joint angle trace

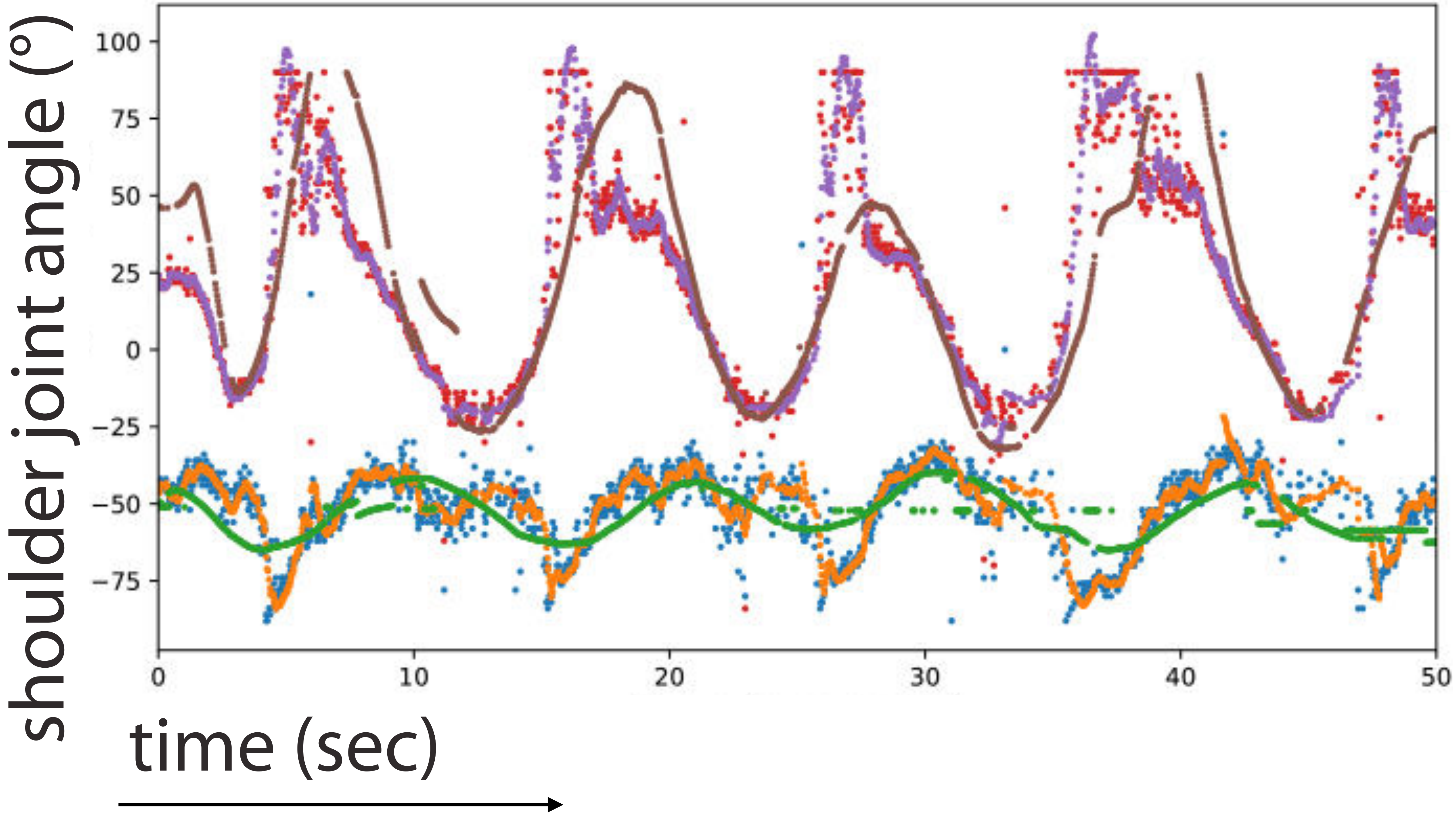


time (sec) →

RF-Wear (Raw) RF-Wear (KF) GroundTruth


shoulder rotation
(3 x 20 sec)
OptiTrack™

shoulder joint angle trace



Horizontal DOF

- RF-Wear (Raw)
- RF-Wear (KF)
- GroundTruth

Vertical DOF

- RF-Wear (Raw)
- RF-Wear (KF)
- GroundTruth

Evaluation Summary

If we use a tag array for 4X2 with an 5cm aperture,

Card board accuracy: 4°

On fabric: 6°-9°

On body: knee 9° (walk in place), 12° (walk around).

elbow 12°, shoulder (21° and 8°)

Context (Kinect): knee joint angle accuracy in a gait cycle: 28.5°

Accuracy of the Microsoft Kinect™ for measuring gait parameters during treadmill walking [Gait & Posture 2015]

discussion

number of tags?

64 on four limbs +
48 on the main body
= 112 tags

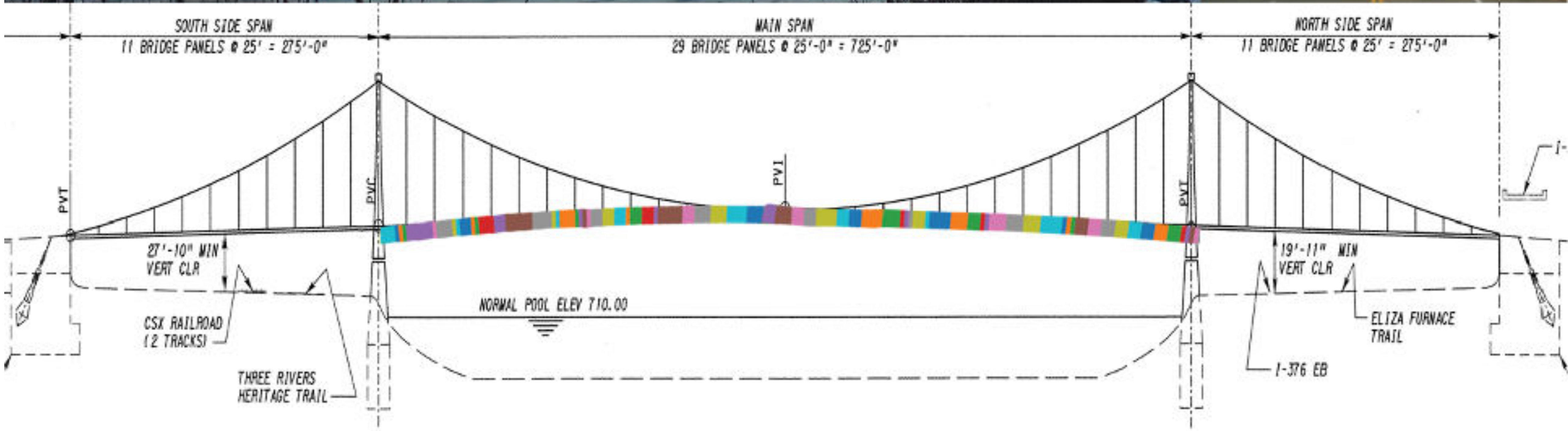

on the fabric


in the fabric


on the body (tattoo)


in the body (implant)

follow-up work



WiSh: Towards a Wireless Shape-aware World using Passive RFIDs (MobiSys'18)

conclusion

body-frame tracking for daily use

turns a regular clothing into a body-frame aware garment

using low-cost, light weight, machine washable, battery-free RFID tags

tracks joint angle at 8~21°, 20~60 Hz

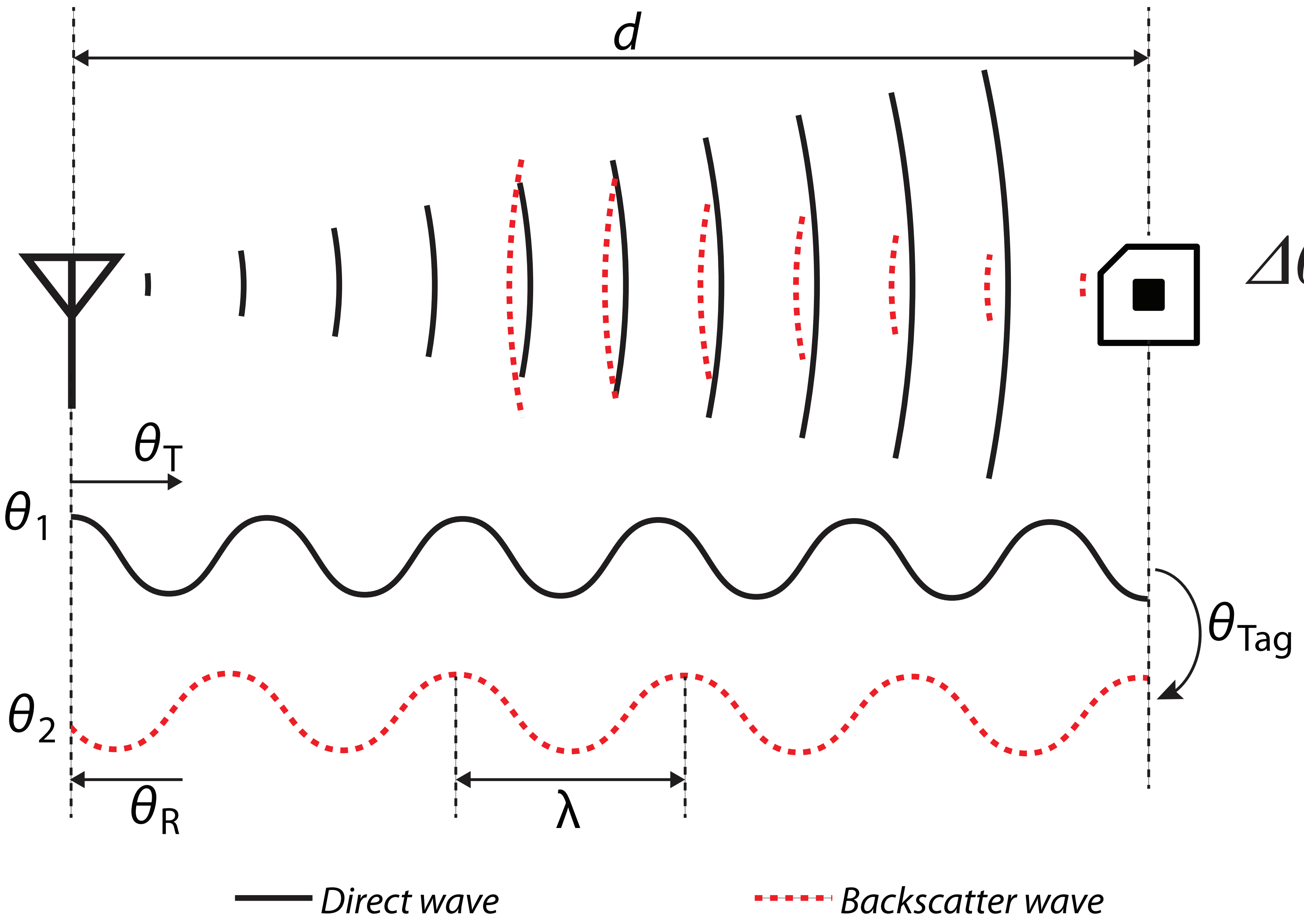
RF-Wear

RF-Wear

Wearable Everyday Body-Frame Tracking using Passive RFIDs

Haojian Jin http://haojianj.in/

Q & A



$$\Delta\theta = \theta_2 - \theta_1$$

$$= \left(\frac{4d\pi}{\lambda} + \theta_T + \theta_{Tag} + \theta_R\right) \bmod 2\pi$$

$$\lambda = \frac{c}{f}$$

Phase in Backscatter Communication

The speed of radio in the air is 3x10^8 m/s.

The 900 MHz radio will have 9x10^8 cycles in one second.

The wavelength (the length of a cycle) would be 33 cm.

The resolution of phase reading is 0.0015 radians.

The distance resolution = $\frac{0.0015}{2\pi} \times 33\ cm$ = 0.0079 cm.

LESS THAN 0.1 mm

Phase to Super Resolution Distance

Mobile Reader (battery up to 8 hours)

Refresh rate

Hardware limit

- reader: 1,100 tags/second.
- RFID tags backscatter frequency on body: 20 Hz.

Software limit:

- MUSIC algorithm is computing expensive: 15 Hz.

https://www.atlasrfidstore.com/impinj-speedway-revolution-r420-uhf-rfid-reader-4-port/

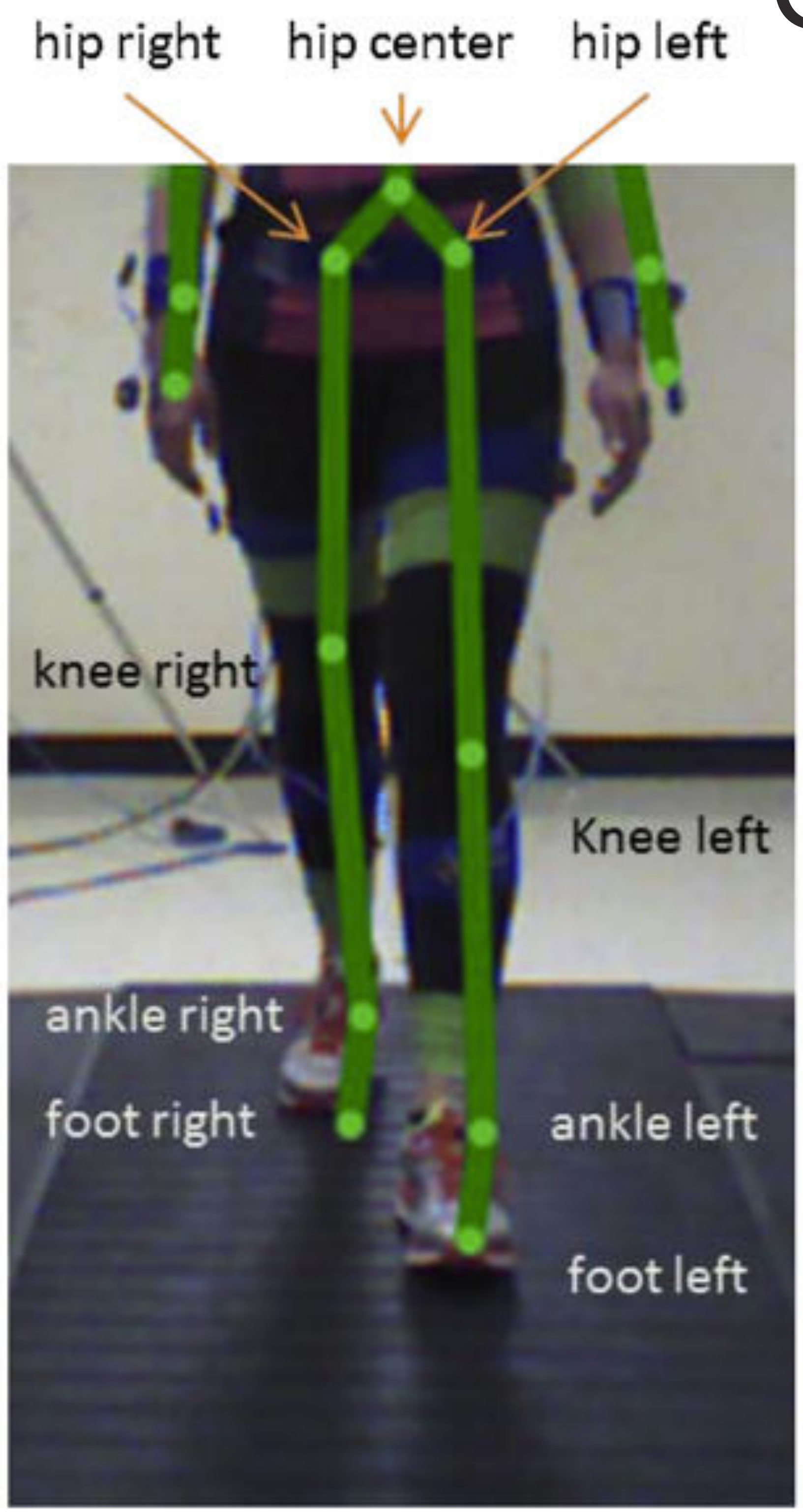
Moving antenna

Each angle computation was run independently based on one observation.

we can do 30~60 Hz with commercial RFID readers

given the reader moves at human speeds.

Context, accuracy of Microsoft Kinect



knee in a gait cycle RMSD: 28.5°

hip RMSD: 11.8°

Accuracy of the Microsoft Kinect™ for measuring gait parameters during treadmill walking [Gait & Posture 2015]

Privacy (radio awareness)

Traditional architecture:
  Stationary readers + Mobile Tags

RFWear, WiSh
  Mobile readers + Mobile/Stationary Tags

Users will have the control and awareness the reader status.

Body-frame v.s. skeleton

RF-Wear tracks the body-frame by tracking the way clothes move as the body moves.

Advantage:
We can also track stomach spasms, belly movement. :)

Limitation:
RF-Wear can only track the joints covered by clothing.