'Novel' Interaction on Mobile Devices

Huaishu Peng | UMD CS | Spring 2026

We have talked about multi-touch screen

What **other components** does a smartphone have
that can be used for interaction?

And **how**?

Speakers

Front Camera

TrueDepth (RGB-D) Sensor

Accelerometer

Gyroscope

Magnetometer

Barometer

Proximity

GPS

NFC

...

Touch Screen Display

Microphones

Speakers

TrueDepth (RGB-D) Sensor

Accelerometer - Acceleration

Gyroscope - Orientation

Magnetometer - Magnetism

Barometer - Air Pressure

Proximity - Distance

GPS - Location

NFC

...

Front Camera

Touch Screen

Microphones

Single user interaction
Multi-user interaction
Sensing beyond interaction

Think as a designer/engineer
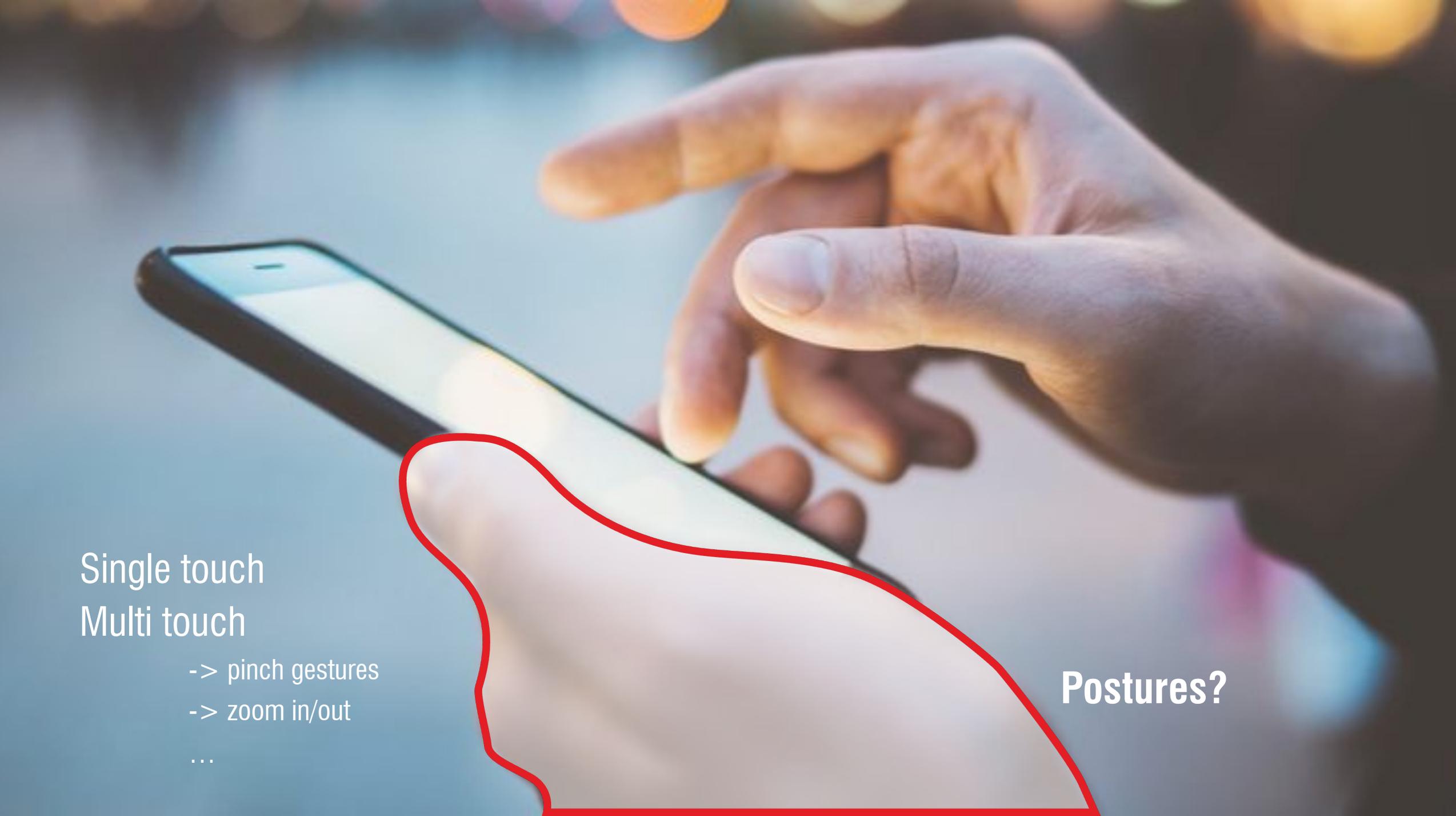Learn different sensing principles + possibilities

Single user interaction
Multi-user interaction
Sensing beyond interaction

Single touch
Multi touch

    -> pinch gestures

    -> zoom in/out

    …

Postures?

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

UIST 2012

Goel et.al. from UW

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

Problem definition: Detect a user's **hand postures** and **touch pressure**

Solution: **touch** info + **IMU**   and   **IMU** + **vibration** motor
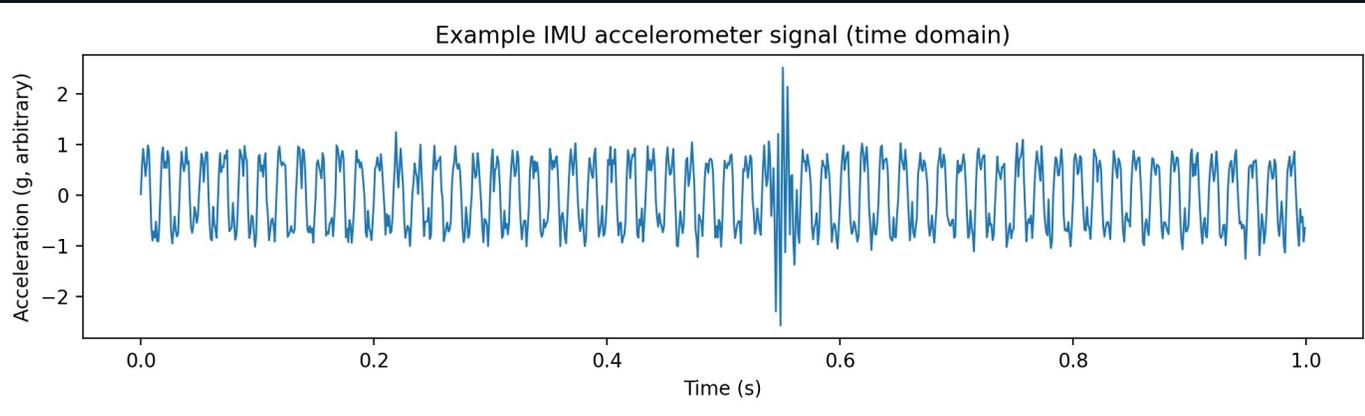
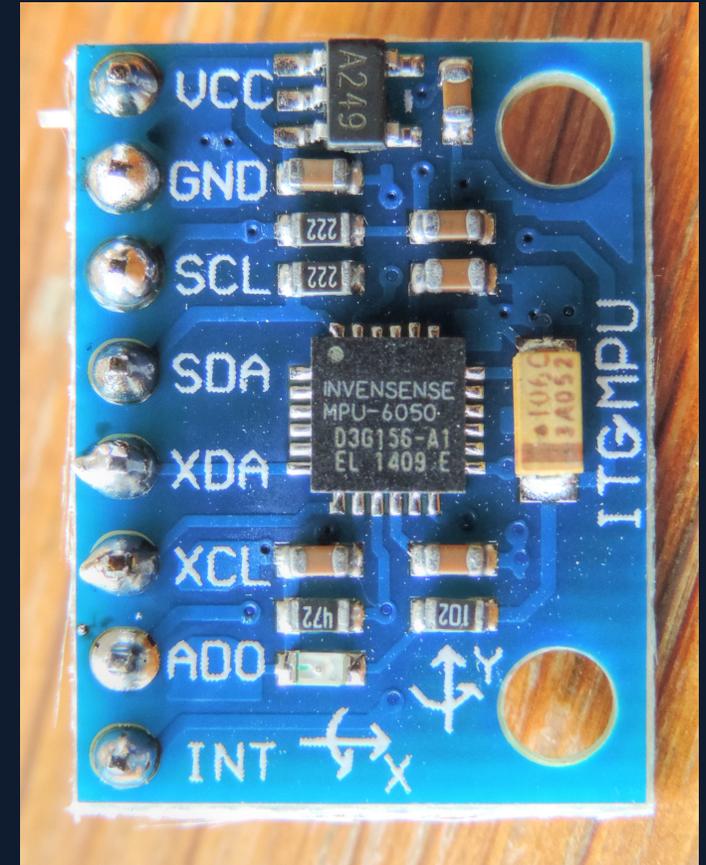# IMU basics

IMU = Inertial Measurement Unit

A sensor module that reports motion from multiple axes.

Typical signals:
- 3-axis accelerometer (specific force / acceleration)
- 3-axis gyroscope (angular rate)
- sometimes 3-axis magnetometer (heading reference)

Example IMU accelerometer signal (time domain)

Example IMU breakout

MPU-6050 module (GY-521)

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

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Shape of swipe arc
Direction of the arc indicates different hands

Shape and position of thumb
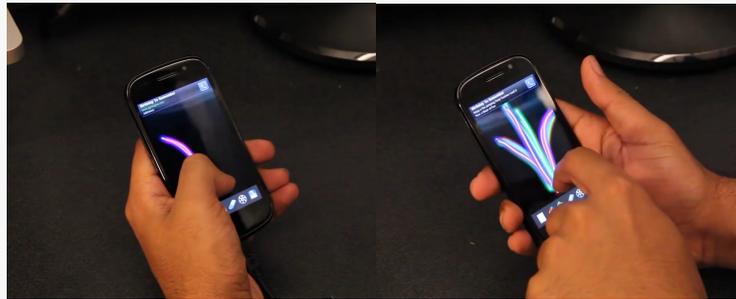Thumb touch size is larger on far side

Rotation of the devices
the phone rotates in response to touches at the top of the screen more than it does to touches at the bottom of the screen

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

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(a) left hand and operated with left thumb

(b) right hand and operated with right thumb

(c) in either hand and operated with the index finger

(d) on a flat surface

(e) being only grasped by the user and not operated.

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones
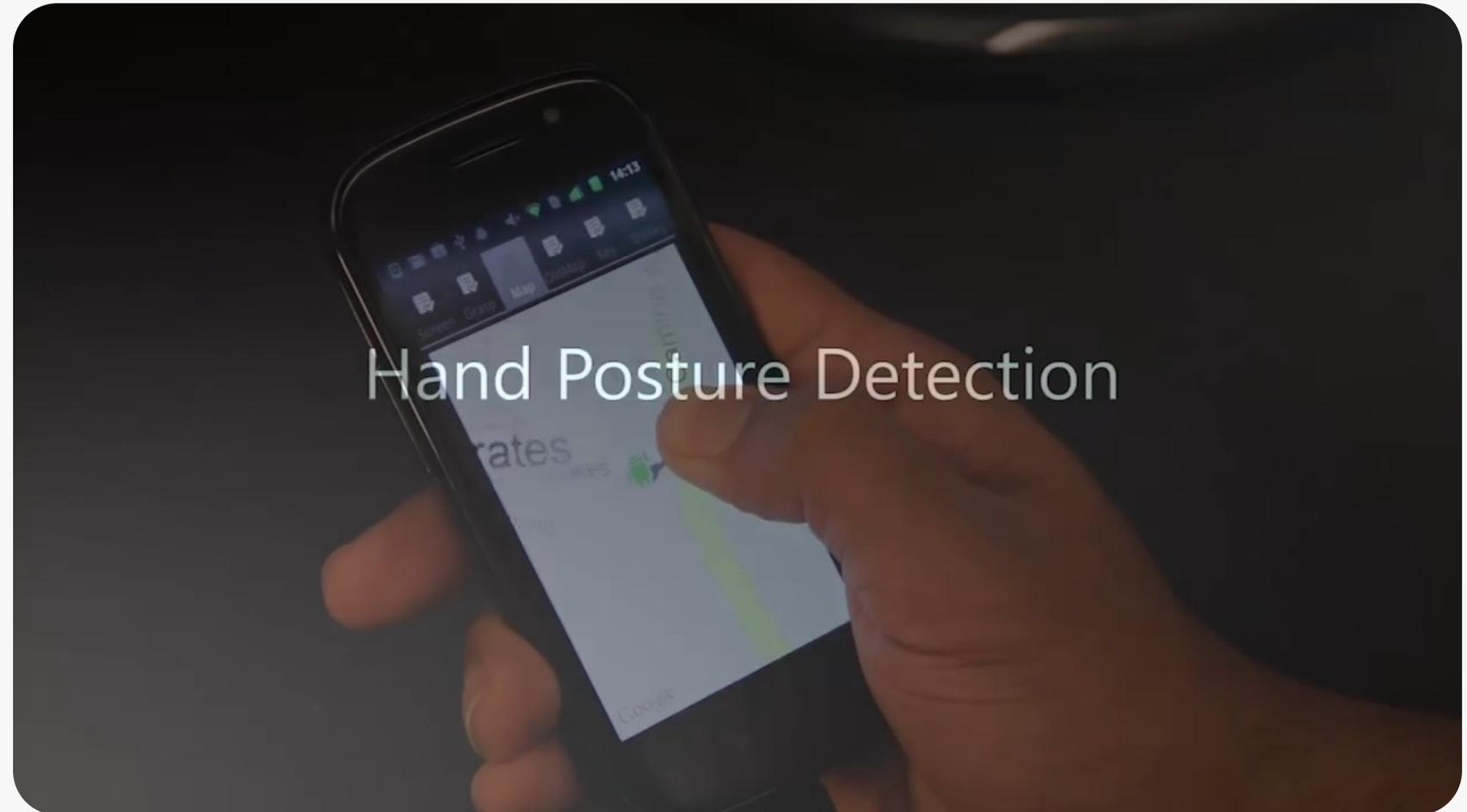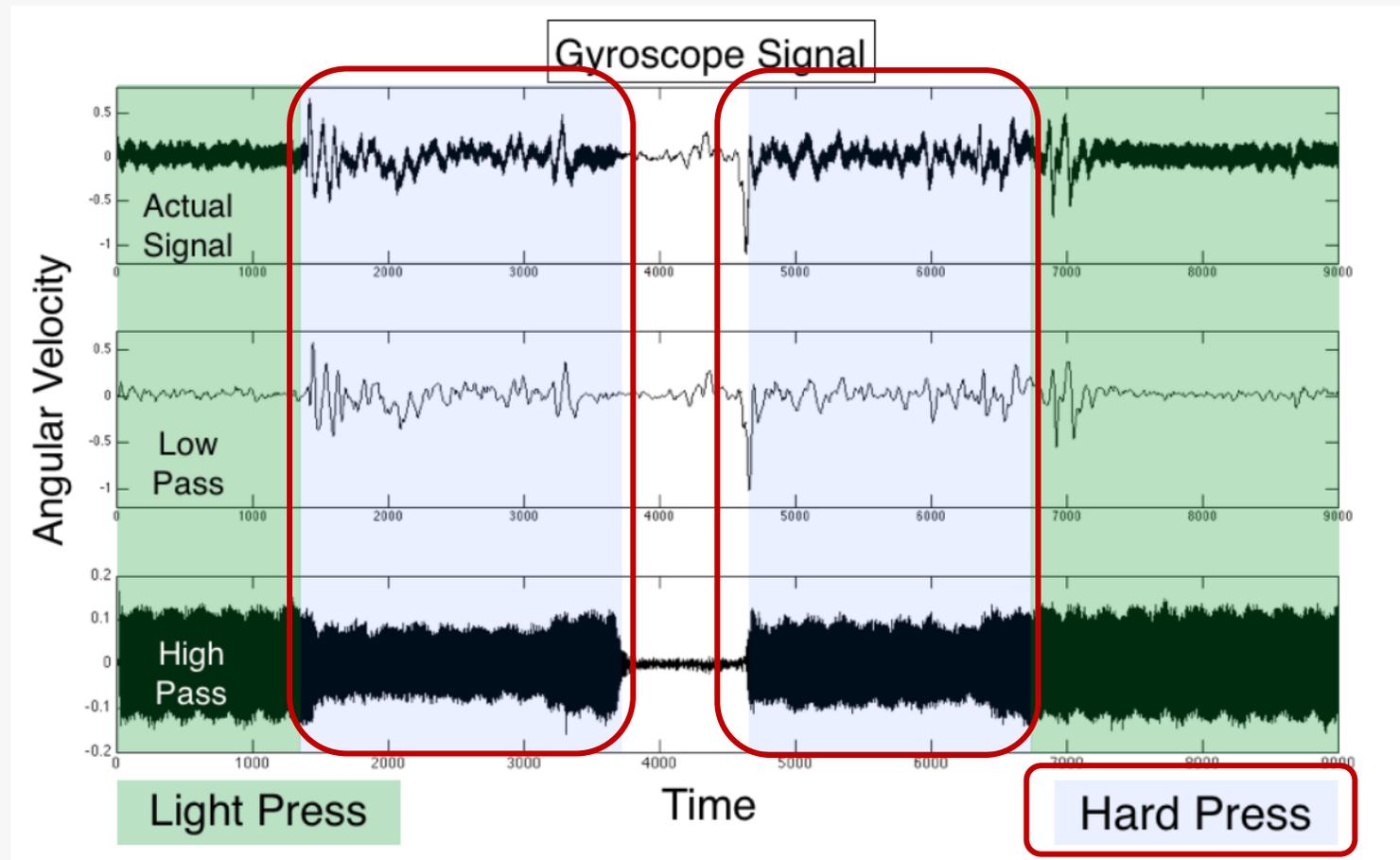
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Key idea:

1) Trigger the **built-in vibration motor** when a user touches the screen
2) The user's hand **absorbs** a portion of these vibrations. (dumping effect)
3) Detect the vibration changes with the **gyro**

note that this is way before the 3D touch available on iPhone

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

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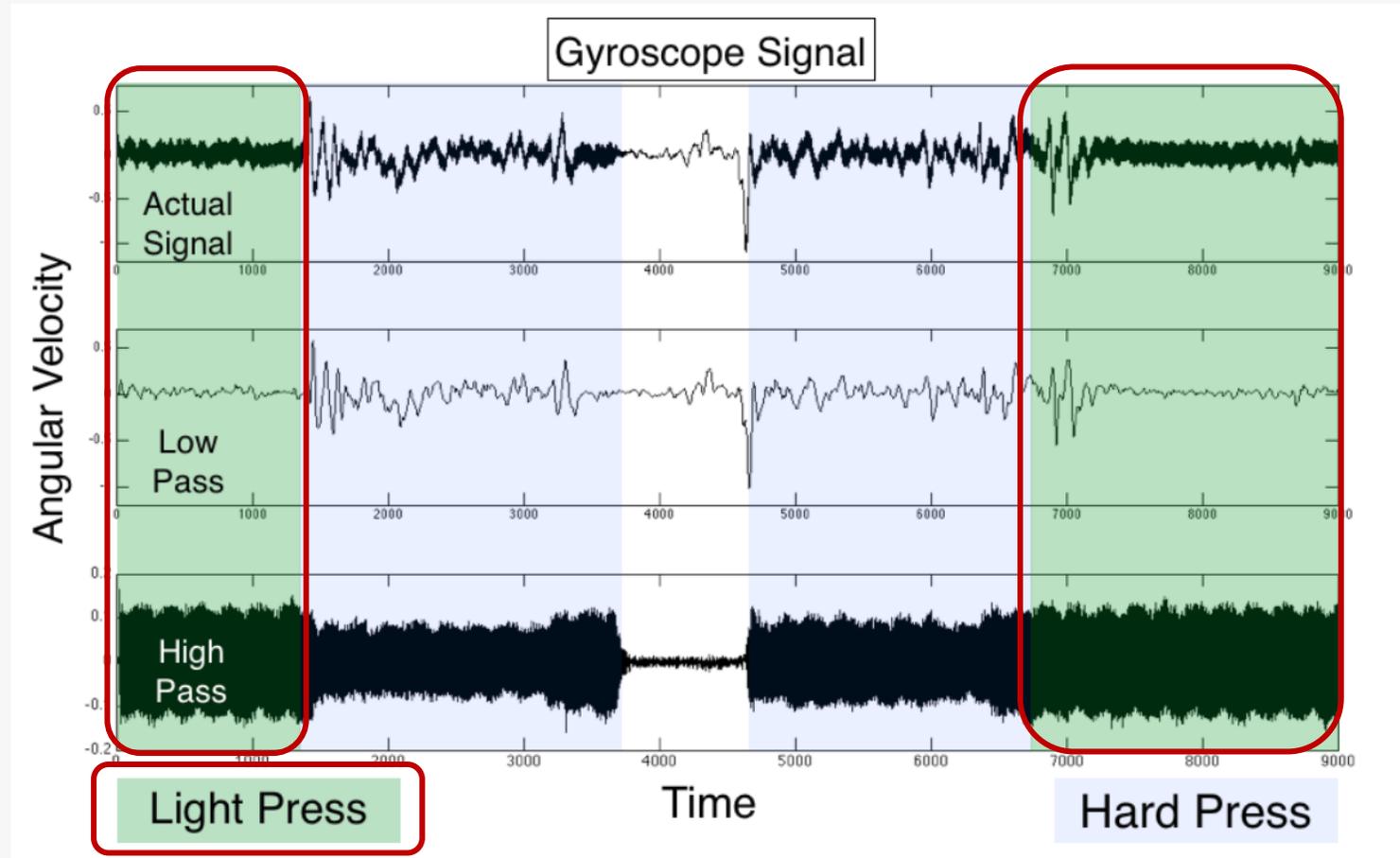
Key idea:

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

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Key idea:

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

Pressure Detection

GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

Applications:
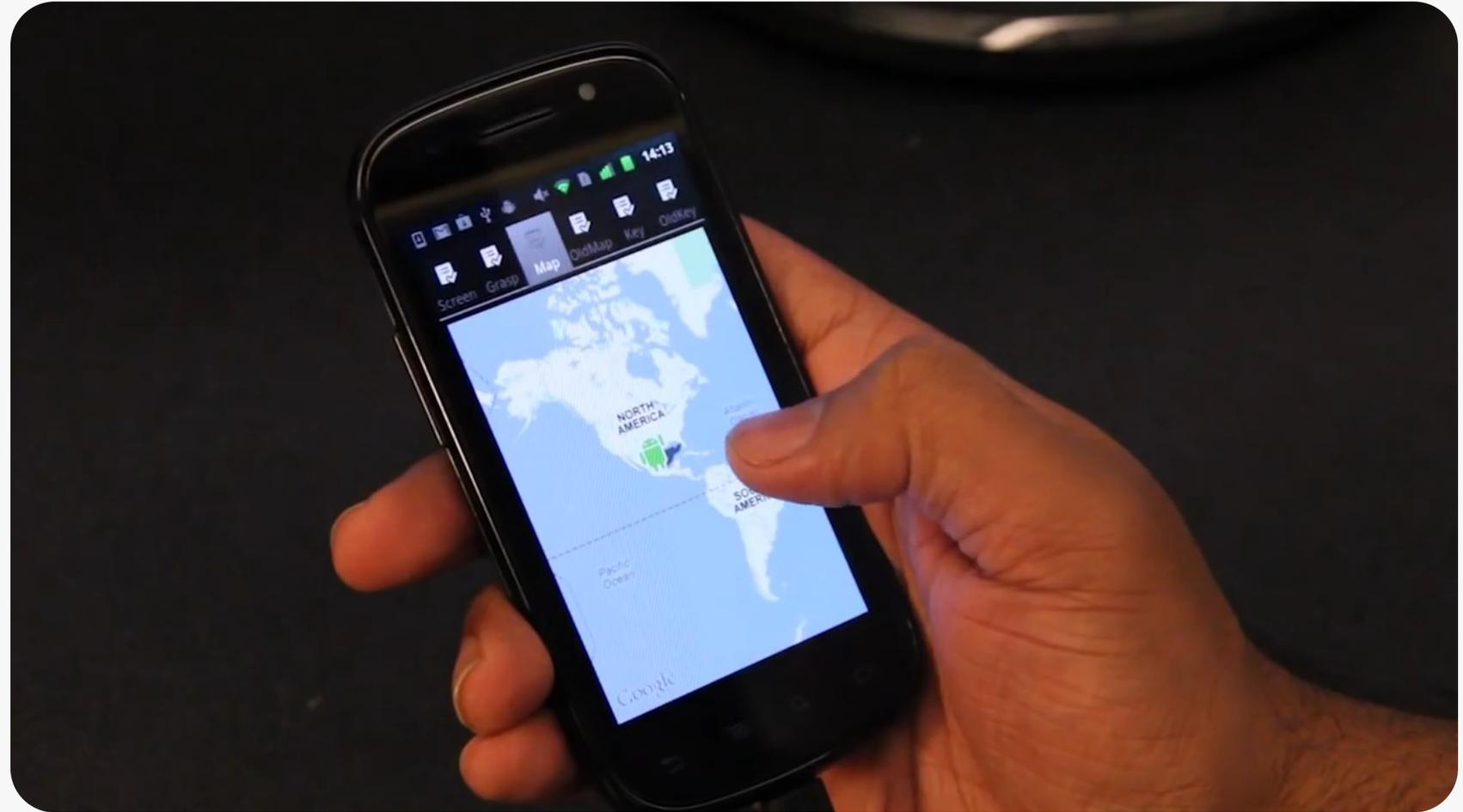
GripSense: Using Built-In Sensors to Detect Hand Posture and Pressure on Commodity Mobile Phones

What makes this work interesting?

Extract **extra** information

(postures + pressure)

 based on **built-in** sensor

Enrich interaction vocabulary
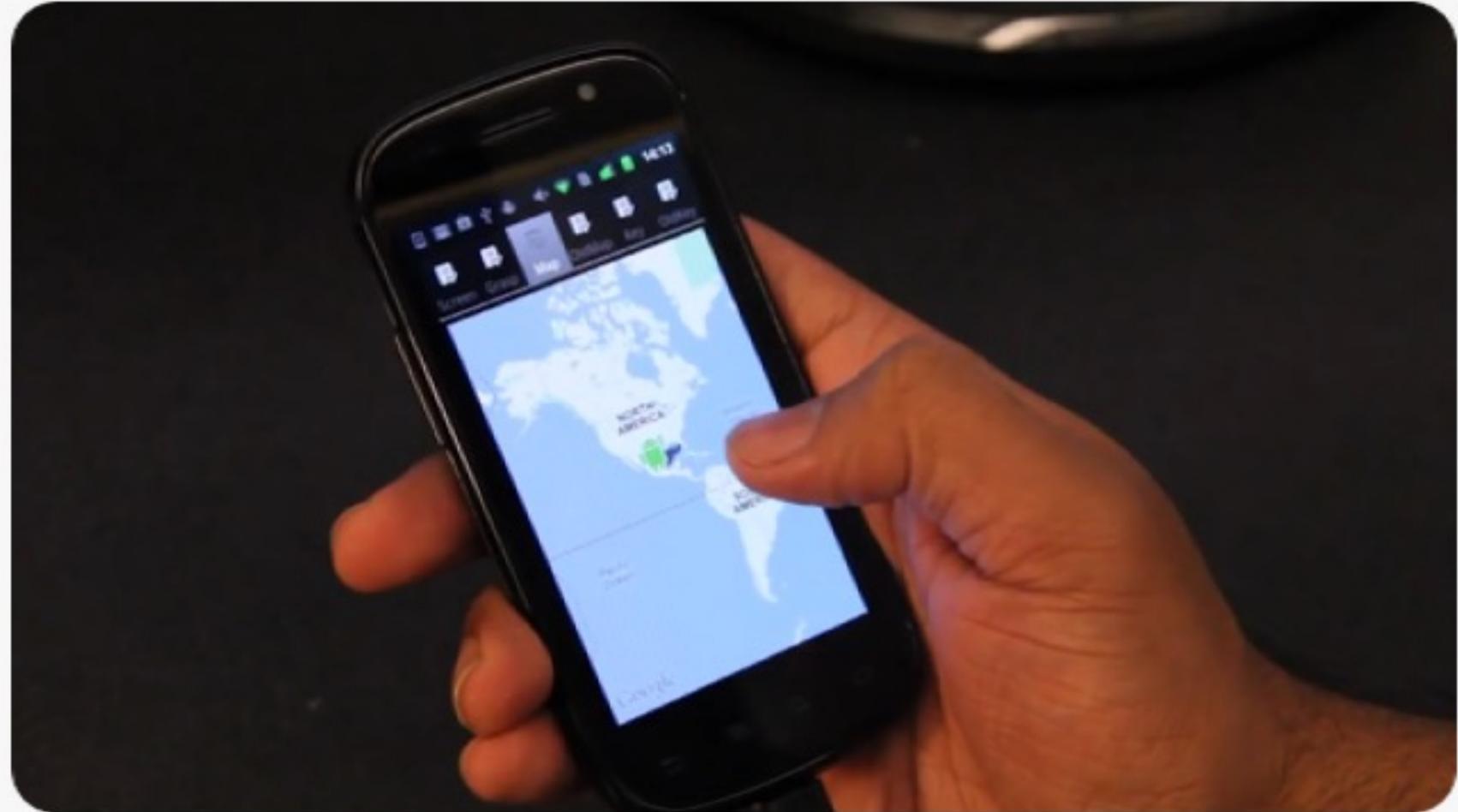
Different part of the finger?

Single touch
Multi touch

    -> pinch gestures
    -> zoom in/out

    …

Postures

TapSense: Enhancing Finger Interaction on Touch Surfaces

UIST 2012
Harrison et.al. from CMU

TapSense: Enhancing Finger Interaction on Touch Surfaces

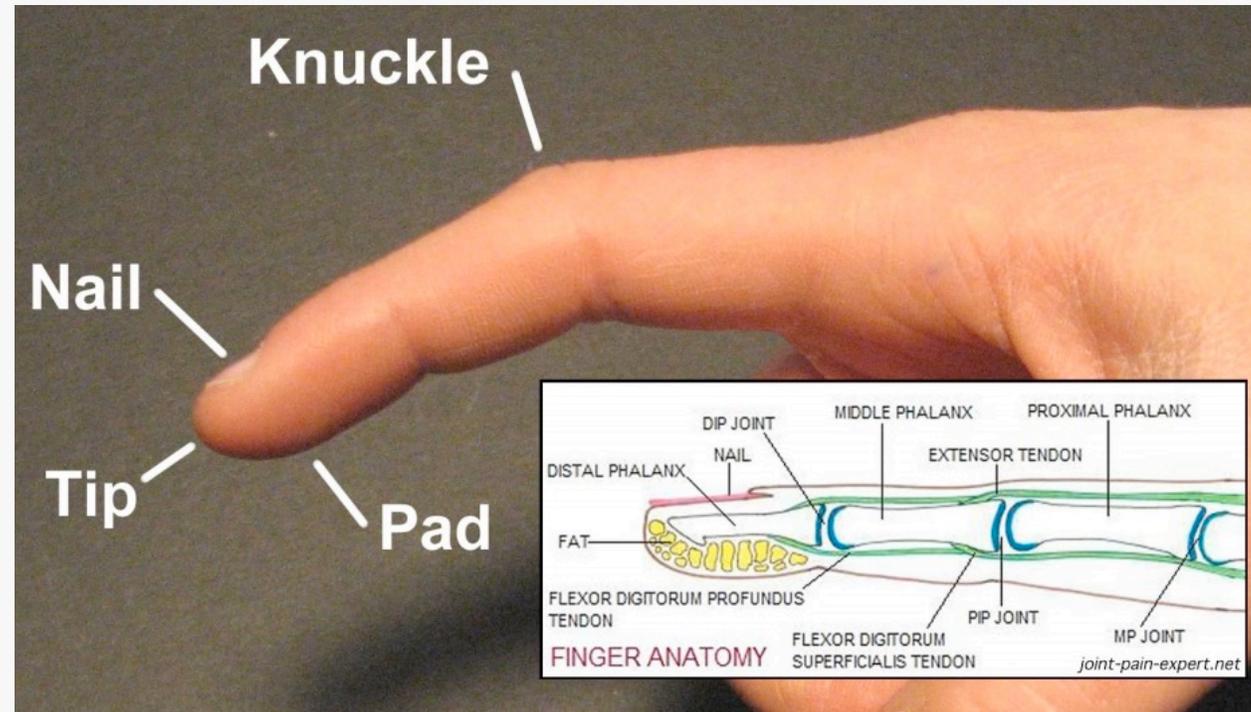Problem definition: Detect a user's interaction with the touchscreen with different part of the finger

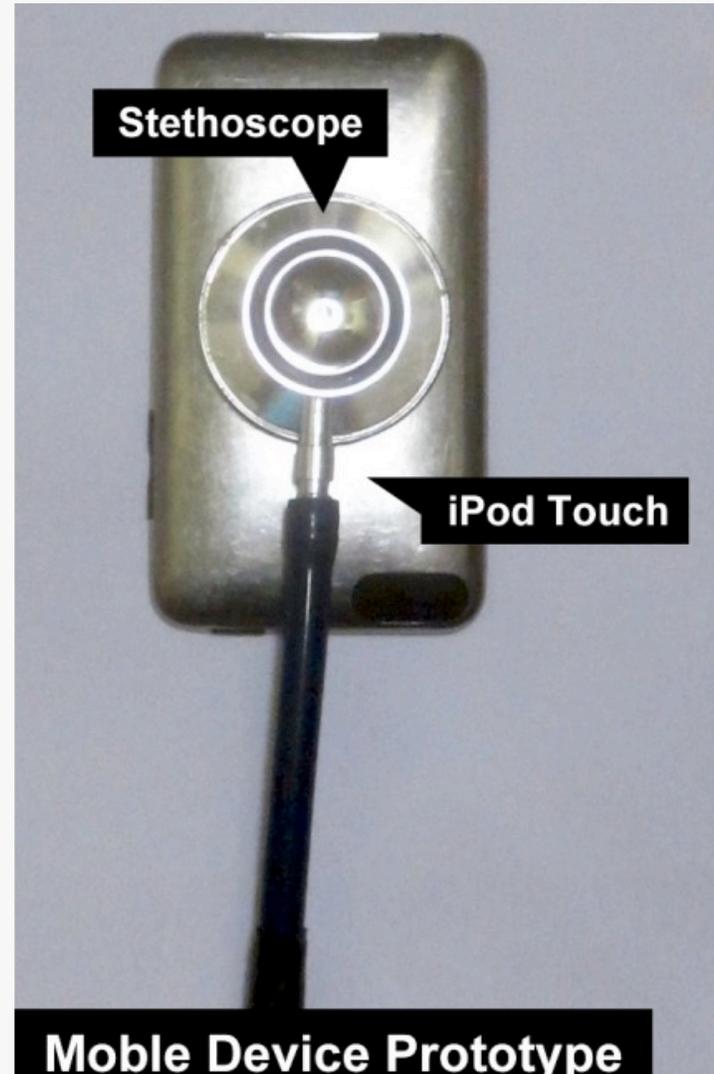**Tip** **Nail** **Knuckle** **Pad**

Observation:

Solution: using **acoustic** features
- different materials produce **different acoustic signatures**
  and have different resonant frequencies

TapSense: Enhancing Finger Interaction on Touch Surfaces

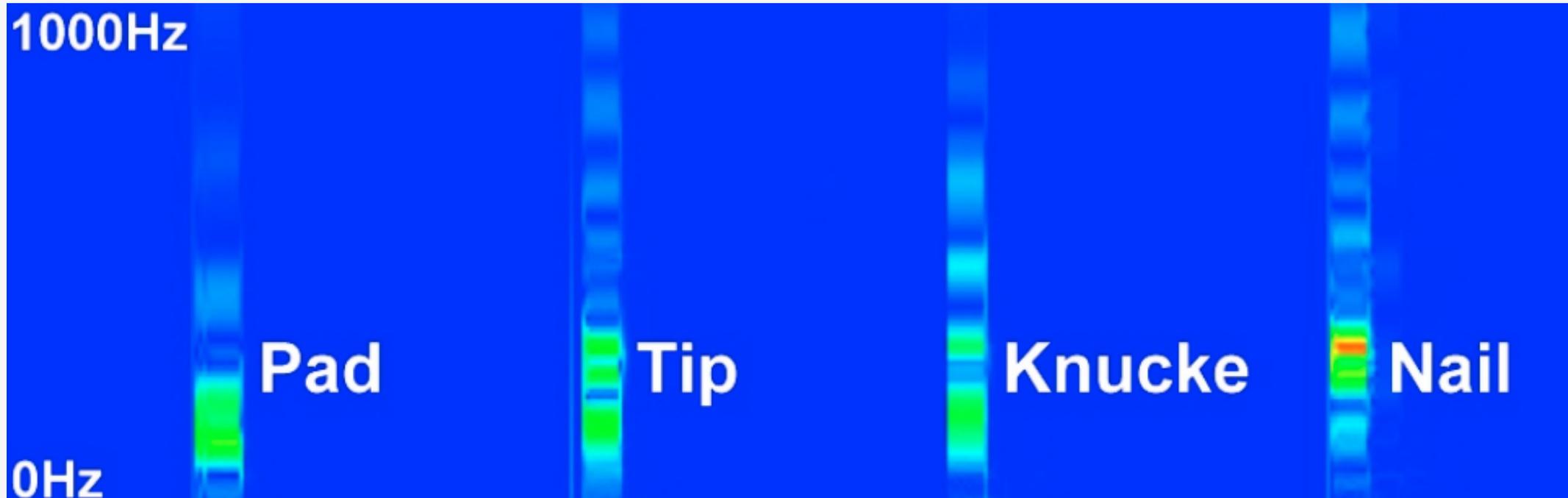Acoustic sensing: Sensing vibration –> Microphone; IMU, etc

For prototyping?

Stethoscope

iPod Touch

Moble Device Prototype

Benefit?
fast and less noise

TapSense: Enhancing Finger Interaction on Touch Surfaces

Acoustic sensing: Sensing vibration   –> Microphone; Accelerometer, etc

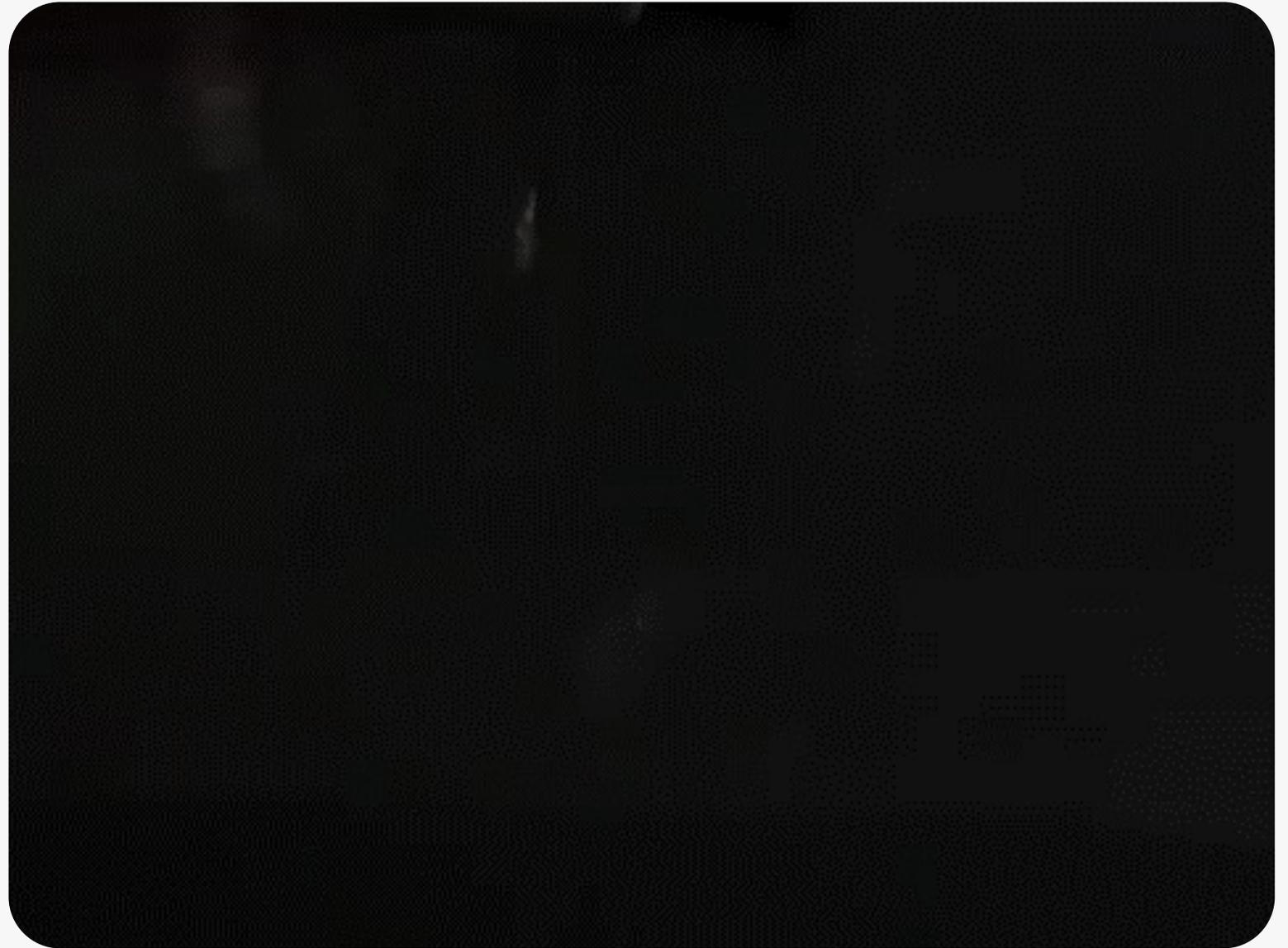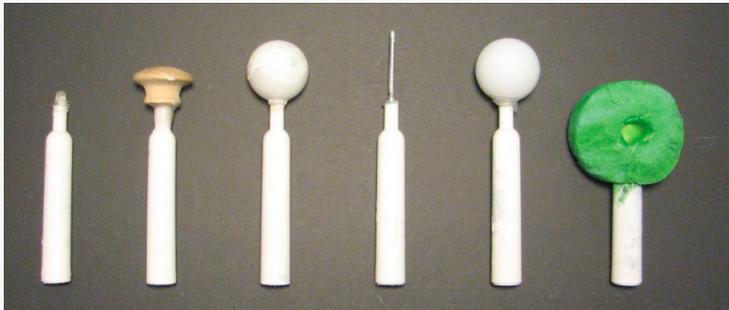Features (amplitude + abs amplitude + FFT…) -> SVM

TapSense: Enhancing Finger Interaction on Touch Surfaces

Enhance interaction:

TapSense: Enhancing Finger Interaction on Touch Surfaces

Passive instruments
Beyond fingers:

TapSense: Enhancing Finger Interaction on Touch Surfaces

What makes this work interesting?

A general approach for enhancing interactions by identifying different parts of a finger.

Product vs Research

TapSense: Enhancing Finger Interaction on Touch Surfaces

Qeexo.com – spin off from CMU

Different part of the finger

Gestures before
and after touch?

Single touch
Multi touch

    -> pinch gestures

    -> zoom in/out

    …

Postures

Air+Touch: Interweaving Touch & In-Air Gestures

Air+Touch: Interweaving Touch & In-Air Gestures

Problem definition : Design **in-air** gestures for mobile interaction

Solution? What if we don't have built-in sensors to sense above screen gestures?

-Using existing tools to simulate the technology in the future

Air+Touch: Interweaving Touch & In-Air Gestures

Problem definition: Design **in-air** gestures for mobile interaction

Solution:
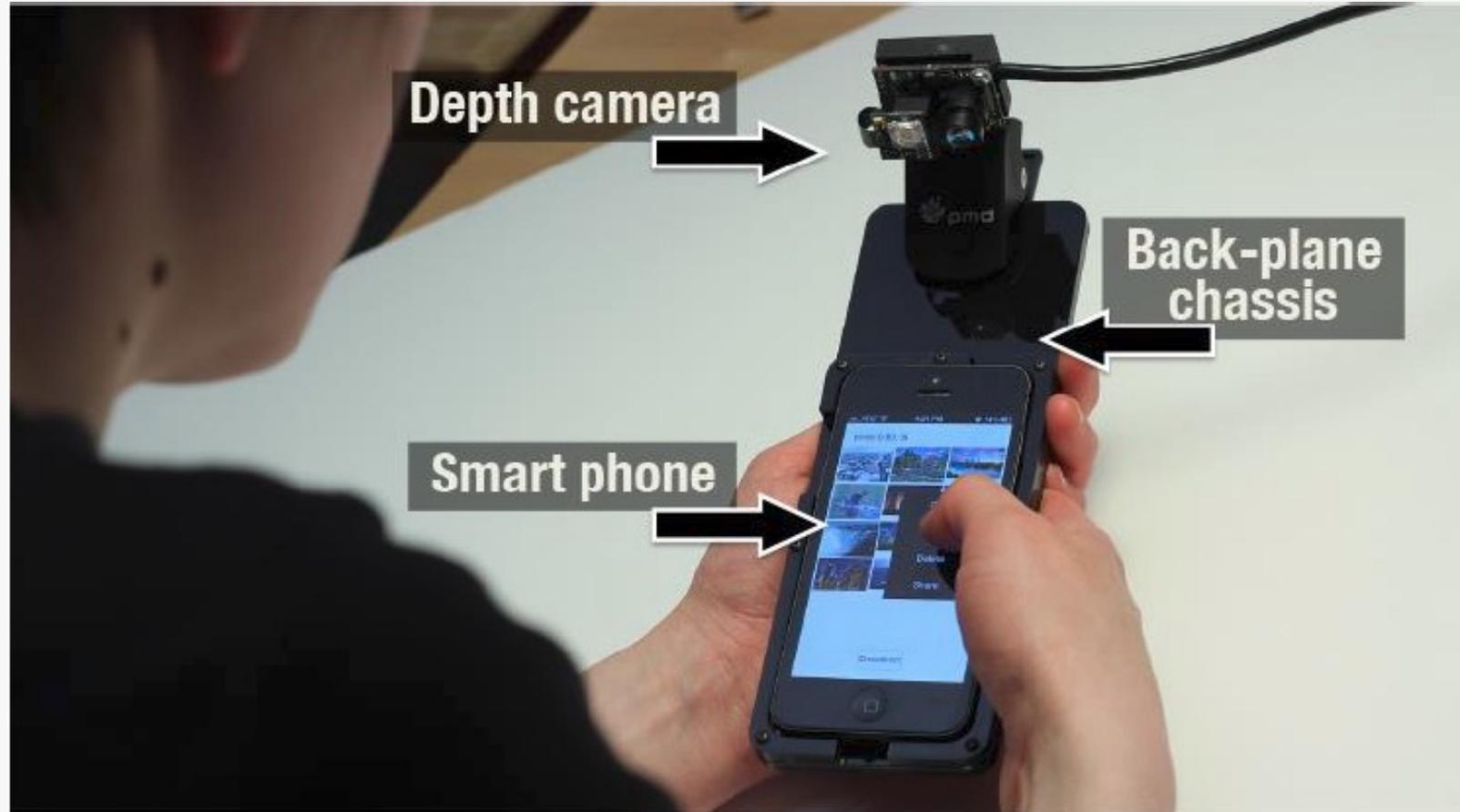
Air+Touch: Interweaving Touch & In-Air Gestures

Interaction Design: Where to start to design in-air gestures?

User study/observation ;)

Participants: 12 (5 female, 7 male, ages 24-36)

Task: to perform a set of common tasks on a smartphone
(e.g., compose a text message, navigate on a map).

Data analysis: Video coding
  -> Distill a set of features that could translate into
  gestural input, while avoiding collisions

Air+Touch: Interweaving Touch & In-Air Gestures

Interaction Design: Where to start to design in-air gestures?
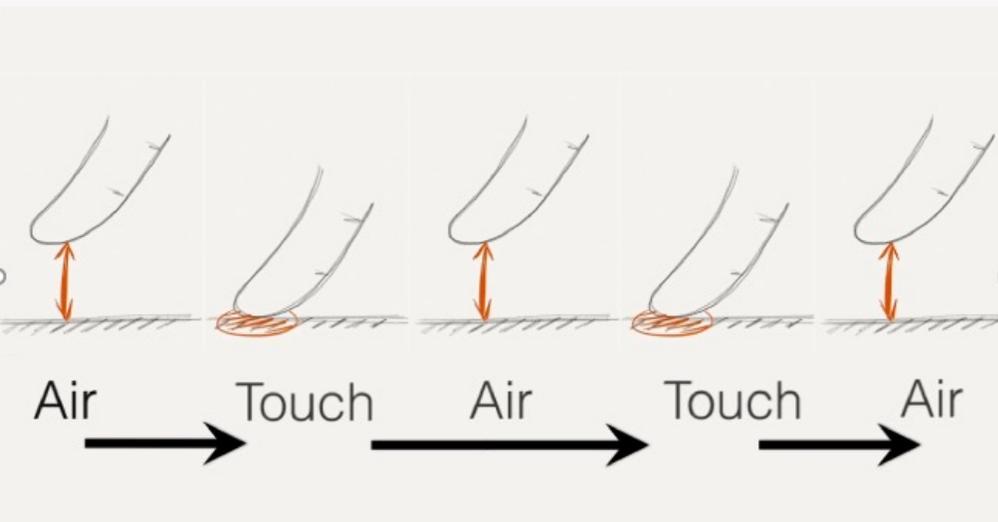
Some of the insights:

Touch event can serve to delimit in-air gestures

Few of the finger motions observed contains elliptical
/rectangular/sharp angle paths

Air+Touch: Interweaving Touch & In-Air Gestures

Interaction Design: Where to start to design in-air gestures?

Some of the insights:

Touch event can serve to delimit in-air gestures
In-air gestures: before, between, after touches

Few of the finger motions observed contains elliptical /rectangular/sharp angle paths
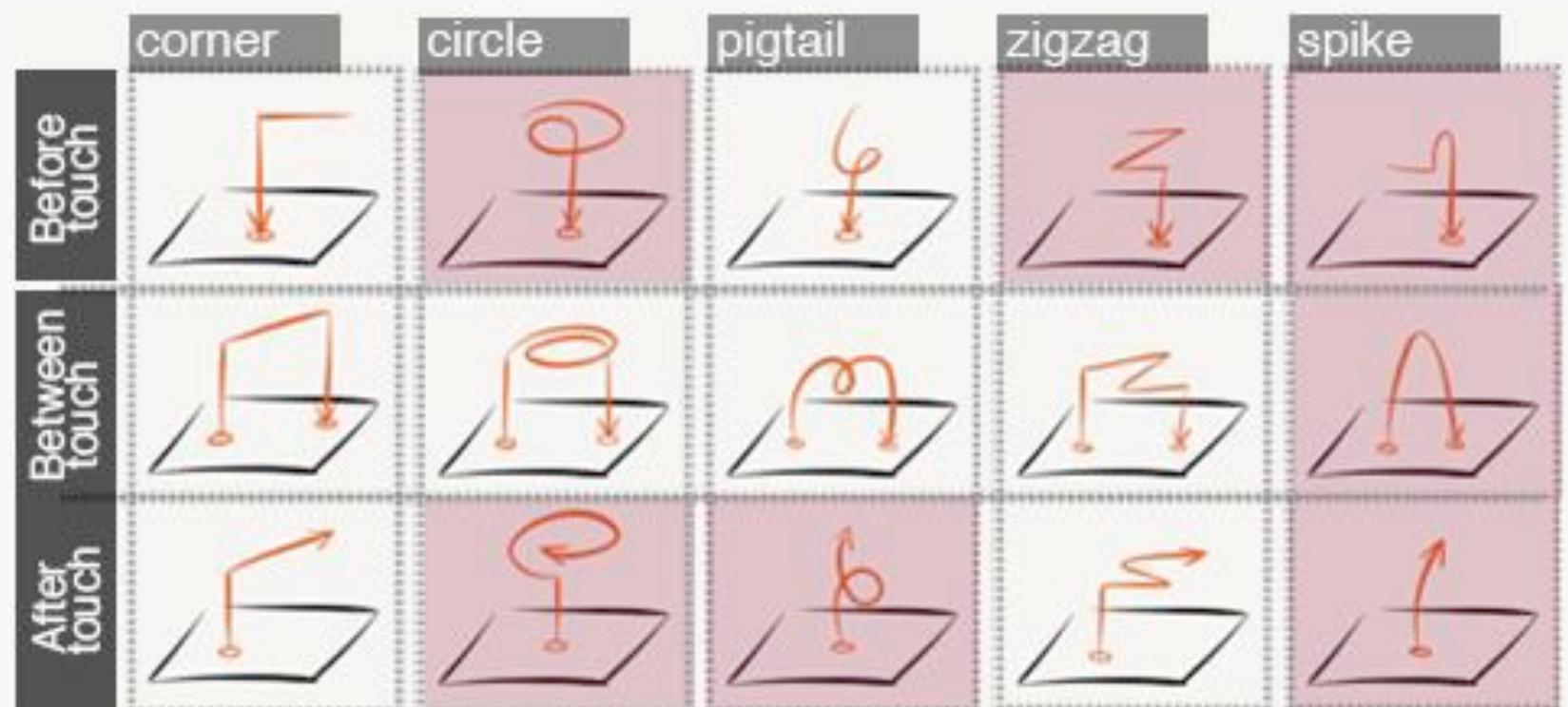**Circular/zigzag paths can be used as in-air gestures**

Air+Touch: Interweaving Touch & In-Air Gestures

Interaction Design: Proof-of-concept gesture vocabulary

Circular/zigzag paths can be used as in-air gestures

In-air gestures:
before, between, after touches

Air+Touch: Interweaving Touch & In-Air Gestures

Examples – Before touch

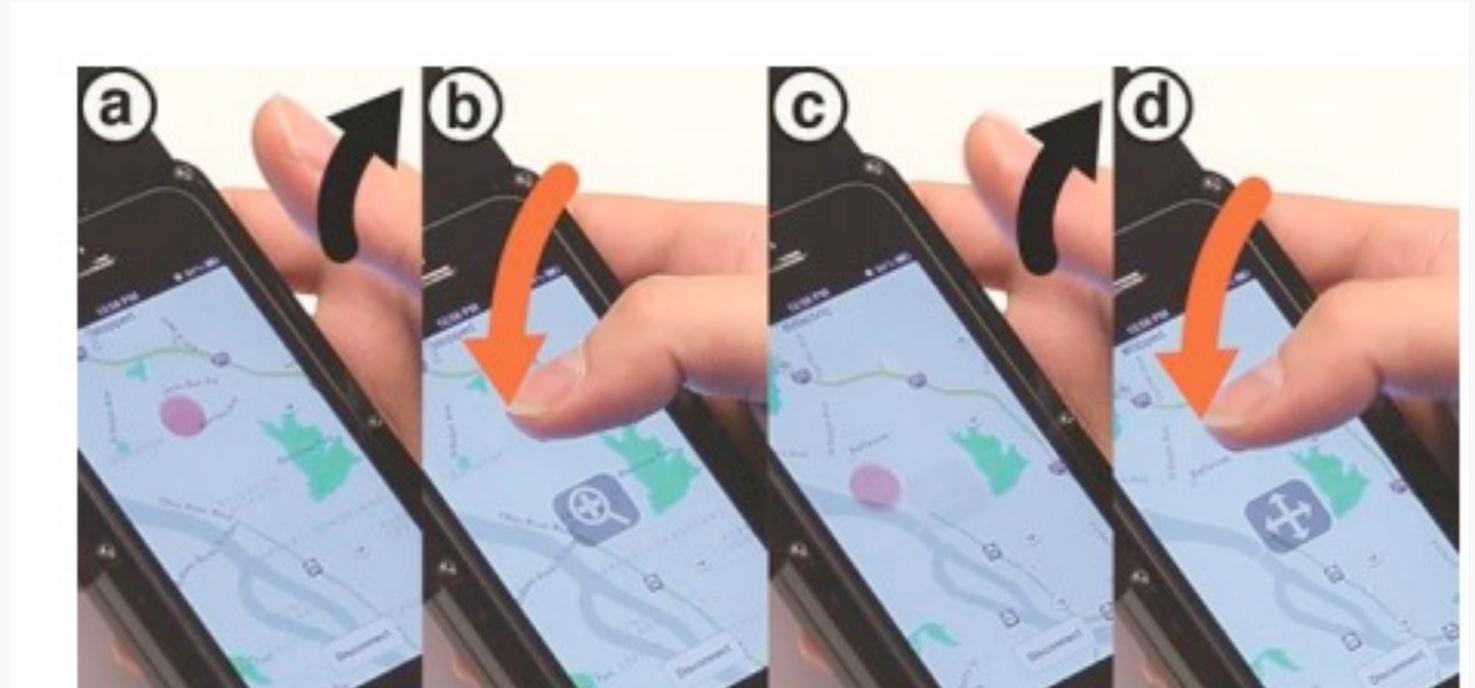Circle in air and tap

High-up and tap for mode switching

Figure 7. In our map app, raising the finger 'high-up' (a, c) before touch down switches between pan/zoom modes (b, d).

Air+Touch: Interweaving Touch & In-Air Gestures

Examples – Air Between Touch

Finger 'high jump' between touches to select text

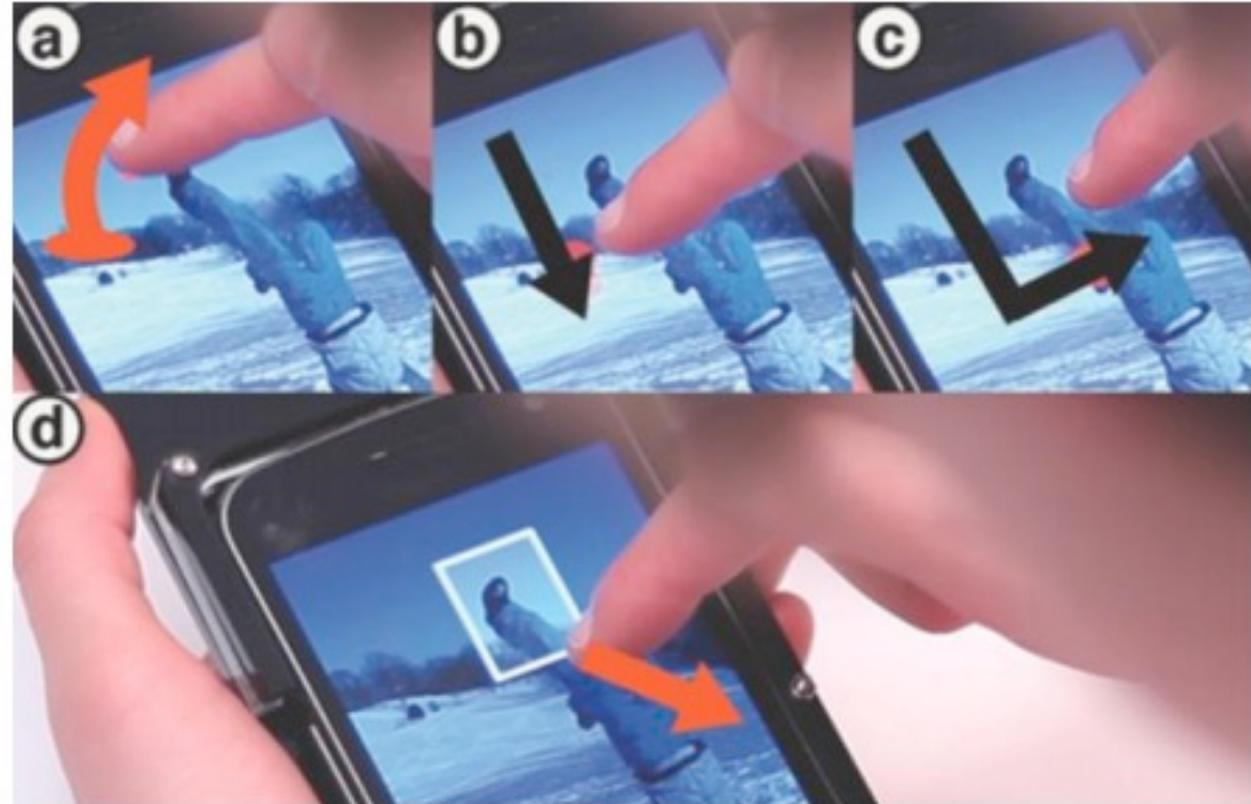Drawing an 'L' between touches for marquee-selection (sub-region of picture)

Figure 9. In the drawing app, a rectangular selection can be made by performing a tap (a), followed by drawing an in-air 'L' gesture (b.c), and finally closed by another tap (d).

Air+Touch: Interweaving Touch & In-Air Gestures

Examples – Air After Touch

Drawing a 'pigtail' after touch
for free-form selection

Cycling in-air after touch to
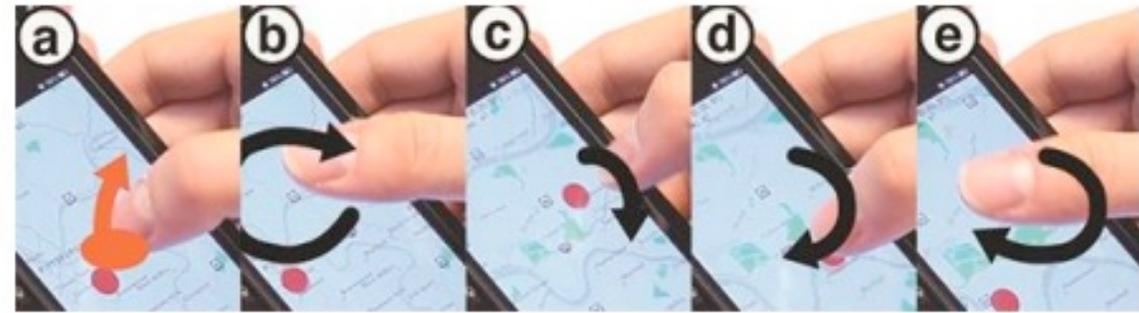zoom on a map

Hovering after touch to change
scroll speed

Figure 11. In our map app, a tap (a) followed by a 'circle' high above the screen (b) allows one to continuously zoom at the map by cycling the finger (c,d,e).
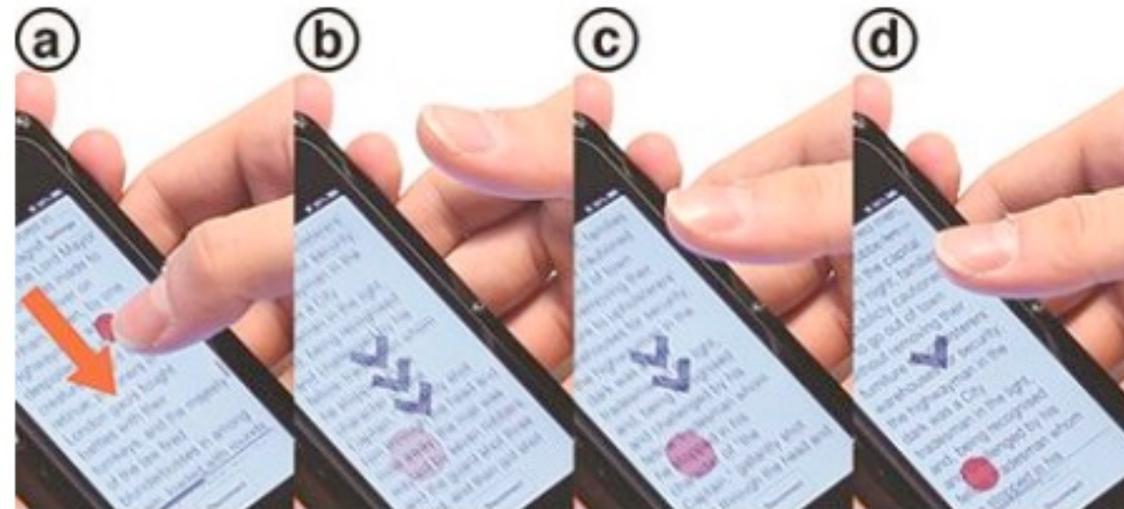
Figure 12. In our reader app, one can use the finger's hover height to control the auto-scrolling speed.

Air+Touch: Interweaving Touch & In-Air Gestures

Is this the end of the work?

What would be the next step?

Single user interaction
Multi-user interaction
Sensing beyond interaction

Single user interaction

Multi-user interaction

Sensing beyond interaction

AirLink: sharing files between multiple devices using in-air gestures

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How does it work?   Doppler shift!

AirLink: sharing files between multiple devices using in-air gestures

How does it work?   Doppler shift

Built-in sensing: Just microphone and speakers

High-frequency sound
(near ultrasound)

Figure 3. By combining 3 basic hand movements: *T* (toward), *A* (away), and *X* (toward and then away), each type of gestures can be represented as a unique codeword.

AirLink: sharing files between multiple devices using in-air gestures

How does it work?   Doppler shift

Built-in sensing: Just microphone and speakers   High-frequency sound
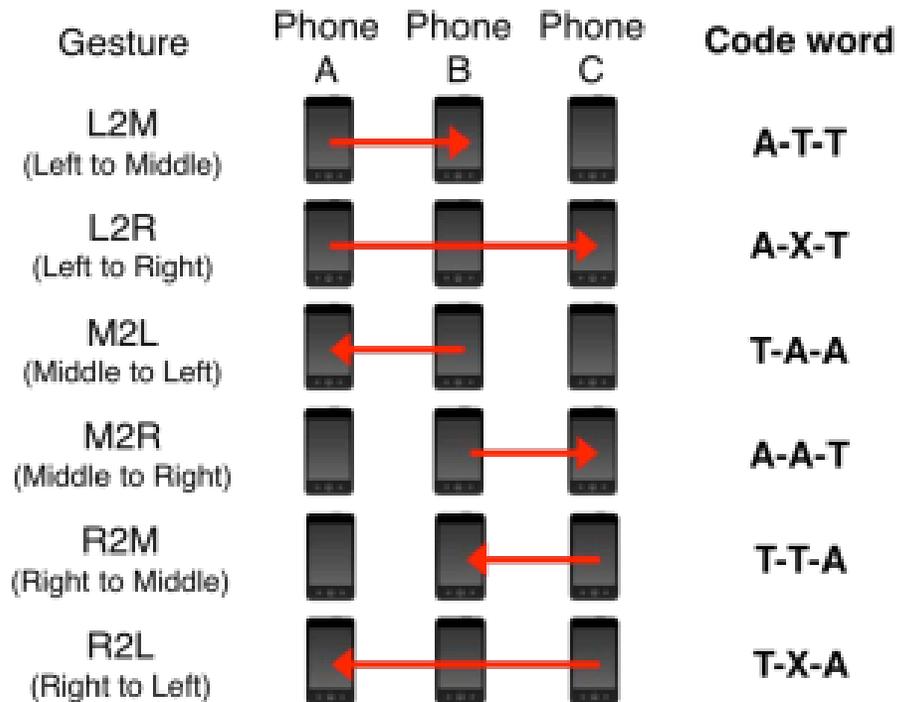(near ultrasound)

Figure 3. By combining 3 basic hand movements: *T* (toward), *A* (away), and *X* (toward and then away), each type of gestures can be represented as a unique codeword.
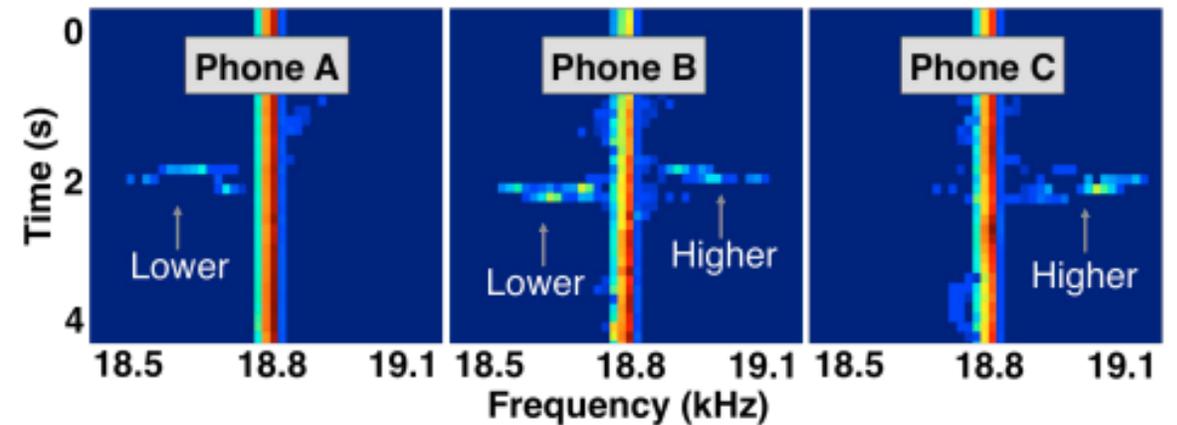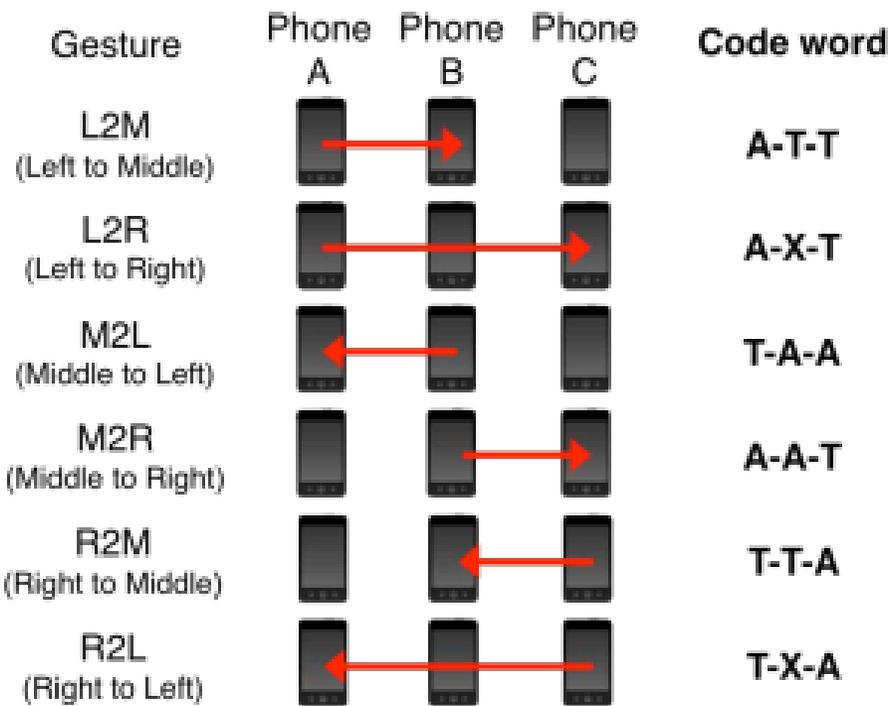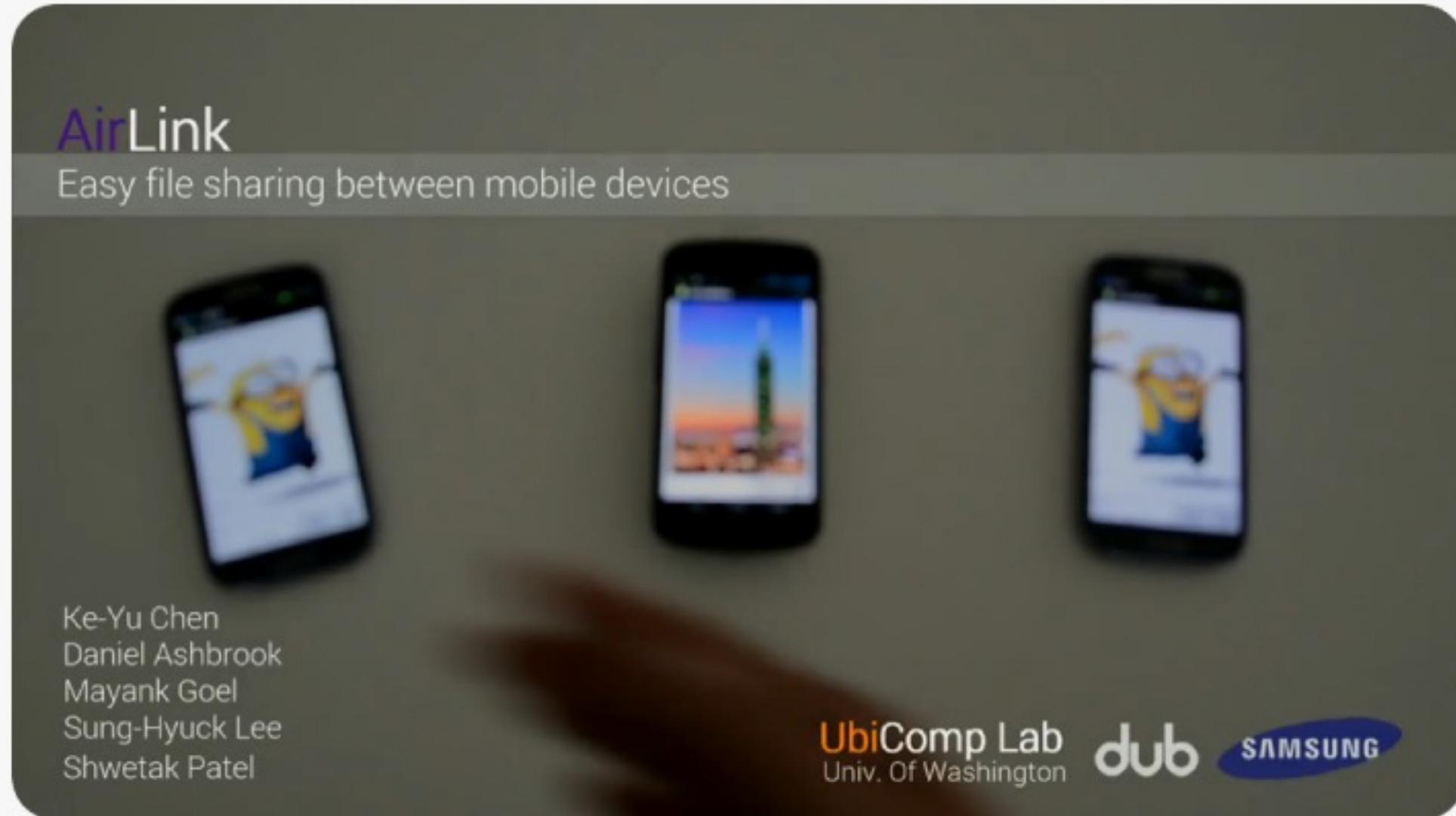

Figure 2. The detected Doppler-shifted signals of a L2R gesture (illustrated in Figure 3). This waterfall plot shows x-axis as frequency and y-axis as time. The pilot tone is emitted at 18.8 KHz on all three phones. On phone B (middle), the shifted frequency first appears on the *right* (higher than the pilot tone) and changes to the *left* (lower than the pilot tone).

AirLink: sharing files between multiple devices using in-air gestures

Limitation?

Limited gesture space
No distance detections

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

UIST 2015

Jin et.al. from Yahoo Labs

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

BLE (only) knows the **presence** of a neighbor device

Tracko knows the **actual locations**

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Fuses 3 signal types on commodity devices

1. Bluetooth low energy (BLE)
2. Inertial motion (gyro+accelerometers, etc)
3. Inaudible stereo signals (ultrasound)

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Bluetooth low energy (BLE)

Robust signal -> detects the **presence** of surrounding devices

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Inertial motion (gyro+accelerometers, etc)

Track each phone's **3D orientations**

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Inaudible stereo signals

Track **distance** between a pair of phones

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

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How does it work?

Inaudible stereo signals

Track **distance** between a pair of phones

$$d_1 = v \times \Delta t$$

v is the **constant** speed of sound.

we can calculate the distance d_1

https://www.youtube.com/watch?v=Bv3c97BYXvE

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction
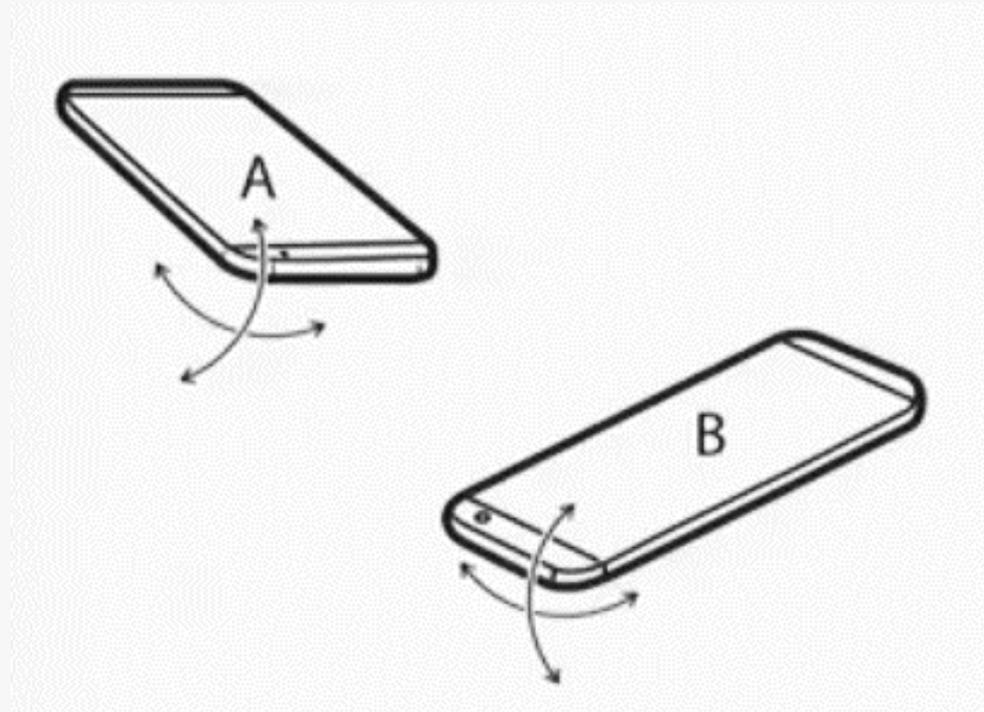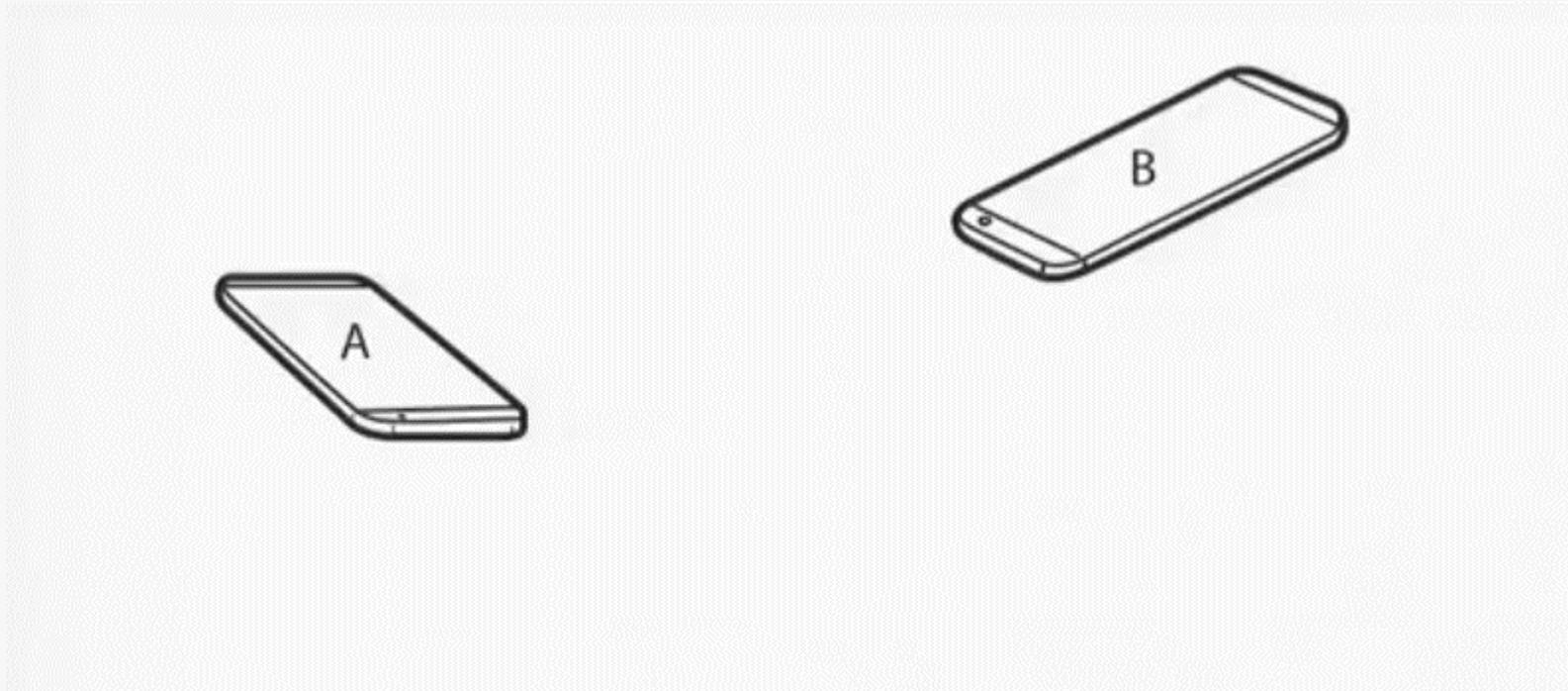
How does it work?

Inaudible stereo signals

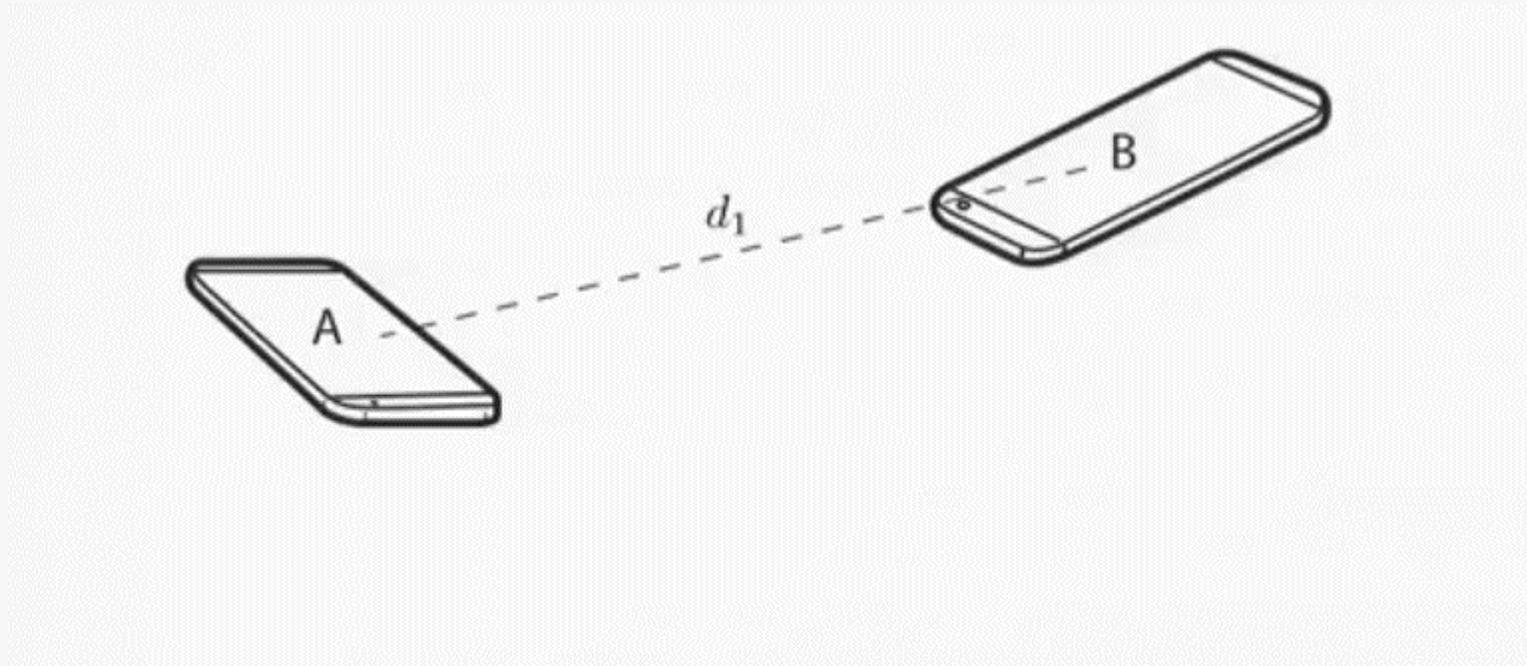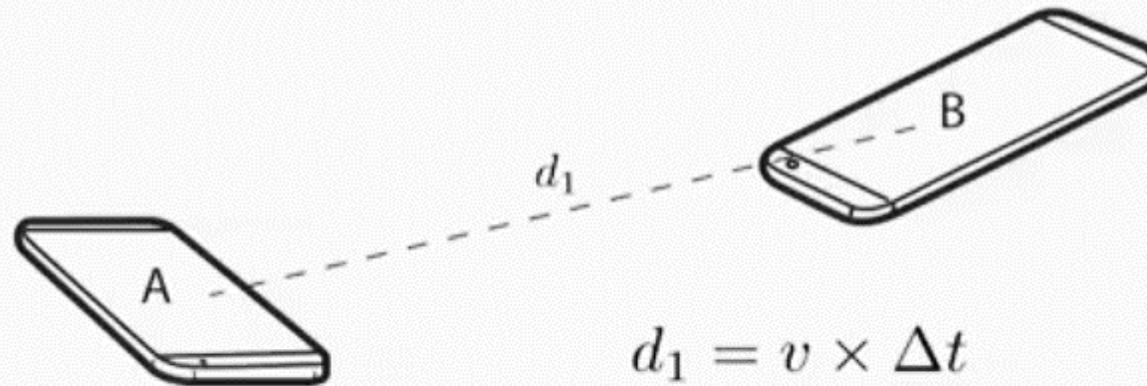Track **distance** between a pair of phones

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Inaudible stereo signals

Track **distance** between a pair of phones

Problem? No time sync between two devices
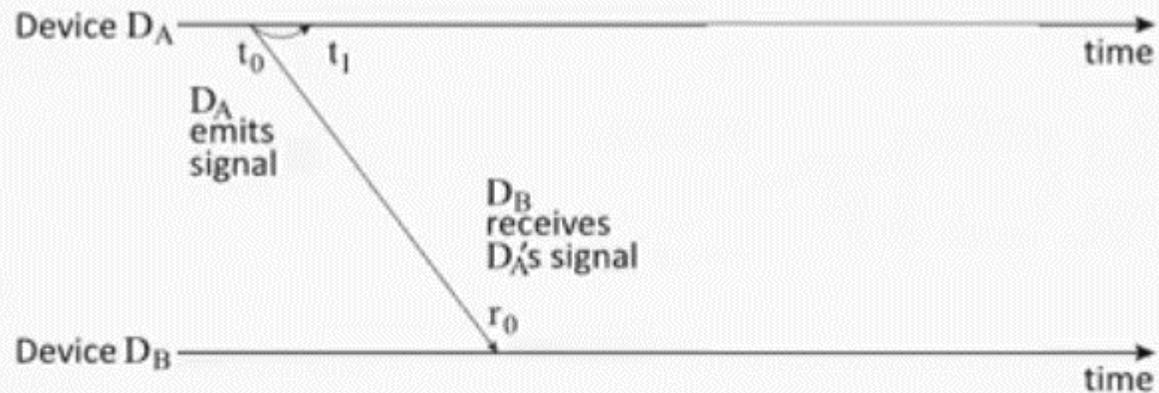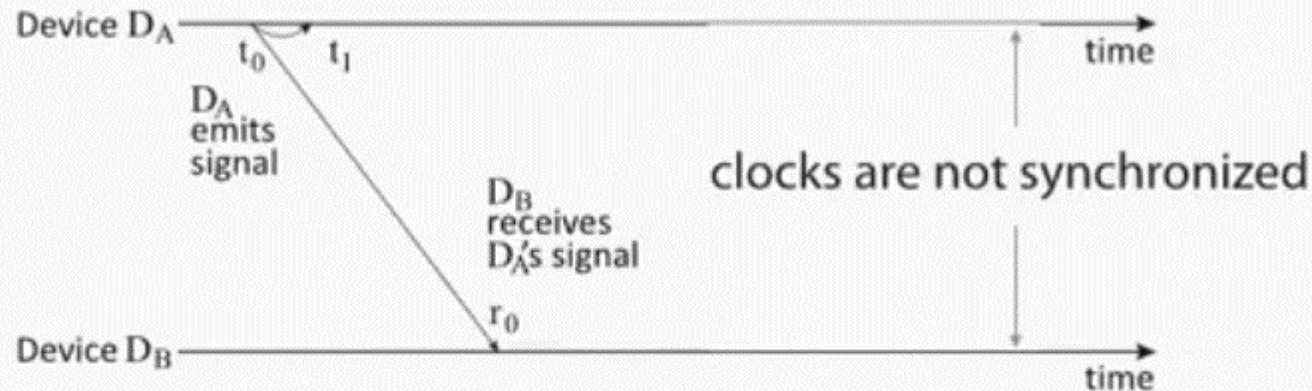
Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Inaudible stereo signals

Track **distance** between a pair of phones

microphone

r_0

B

d_2

microphone

r_1

A

d_1

t_2

speaker

t_0

speaker

$$d_1 = v \times (r_0 - t_0)$$

$$d_2 = v \times (r1 - t2)$$
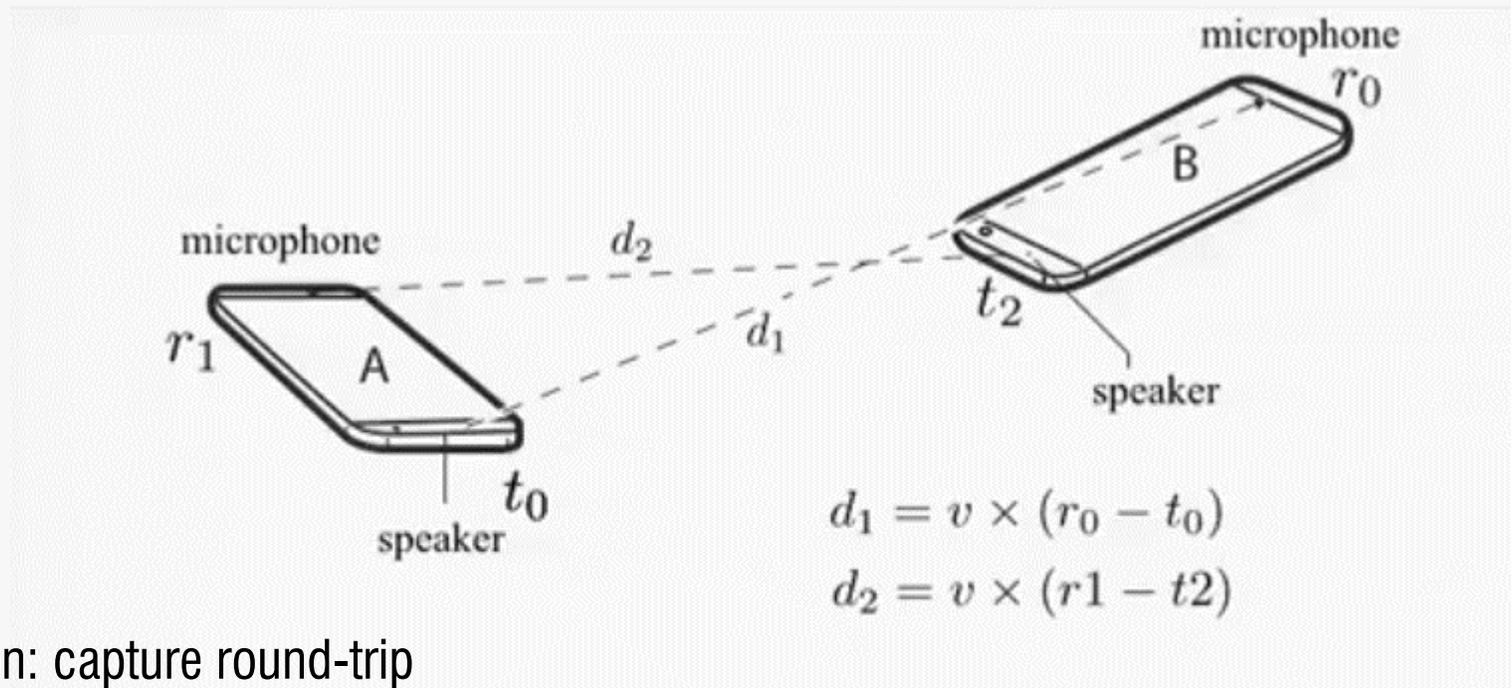
Solution: capture round-trip

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Inaudible stereo signals

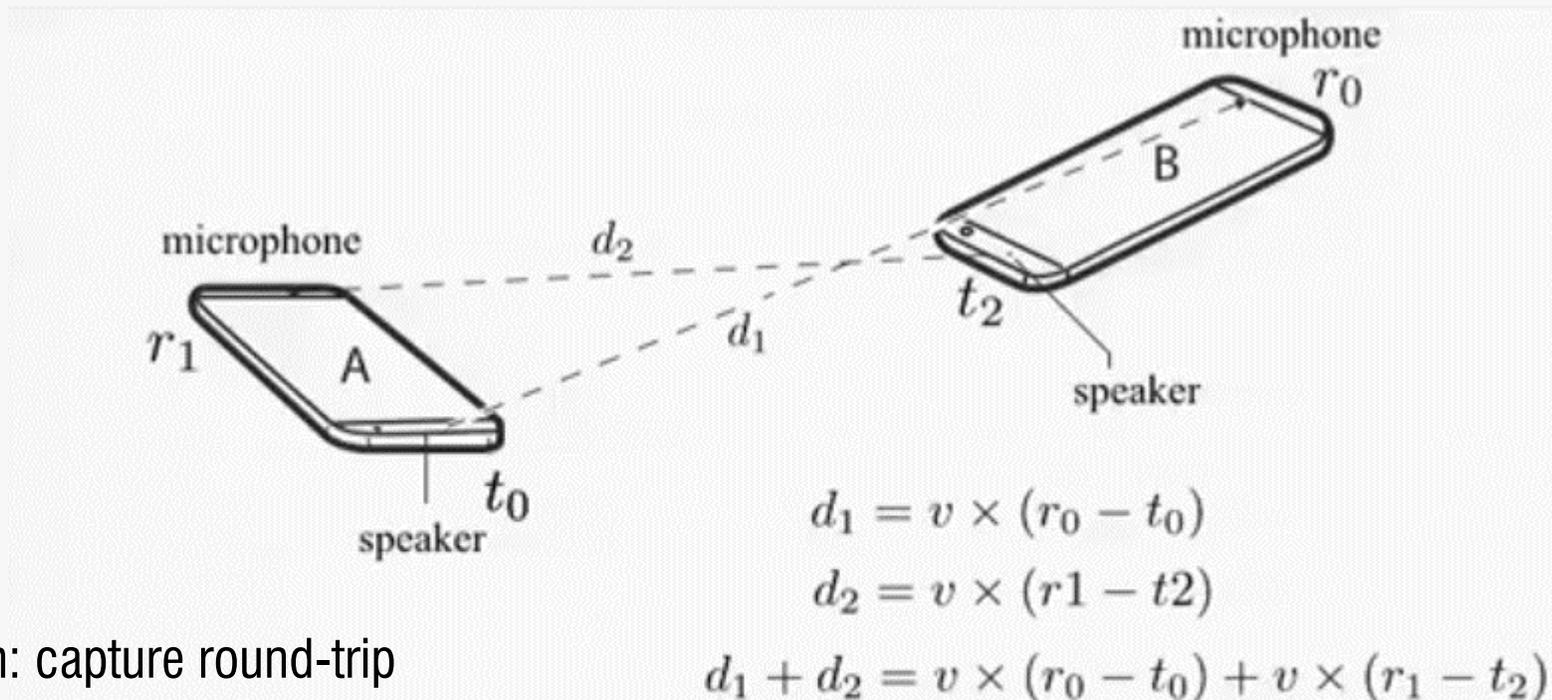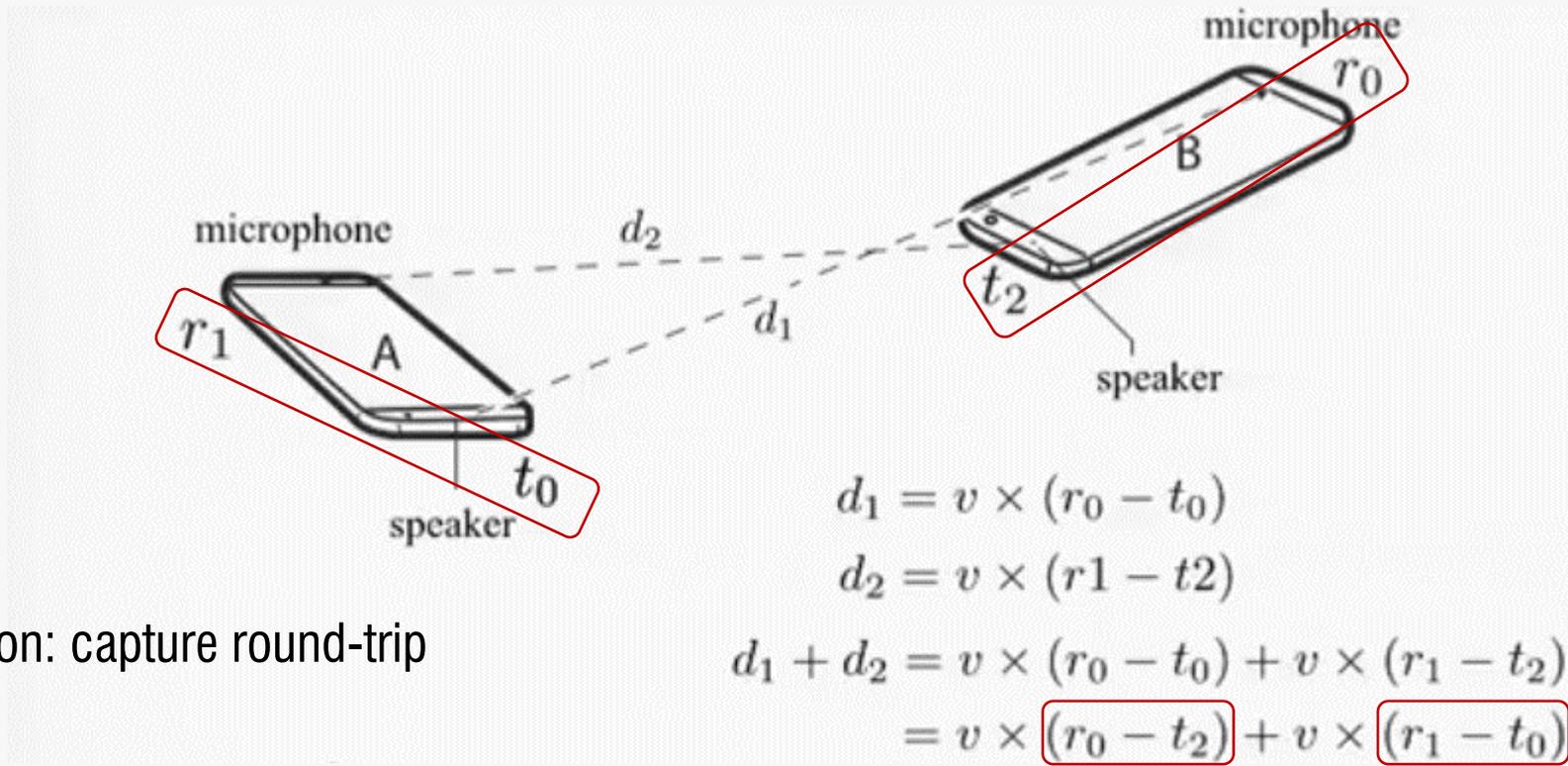Track **distance** between a pair of phones

microphone

r_0

B

microphone

d_2

t_2

r_1

A

d_1

speaker

t_0

speaker

$$d_1 = v \times (r_0 - t_0)$$

$$d_2 = v \times (r1 - t2)$$

Solution: capture round-trip

$$d_1 + d_2 = v \times (r_0 - t_0) + v \times (r_1 - t_2)$$

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Inaudible stereo signals

Track **distance** between a pair of phones

microphone

r_0

B

microphone

d_2

t_2

r_1

A

d_1

speaker

t_0

speaker

$d_1 = v \times (r_0 - t_0)$

$d_2 = v \times (r1 - t2)$

Solution: capture round-trip

$d_1 + d_2 = v \times (r_0 - t_0) + v \times (r_1 - t_2)$

$= v \times (r_0 - t_2) + v \times (r_1 - t_0)$

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

How does it work?

Fuses 3 signal types on commodity devices

1. Bluetooth low energy (BLE) -> coarse presence
2. Inertial motion (gyro+accelerometers, etc) -> phone orientation
3. Inaudible stereo signals (ultrasound) -> 3D offset

Tracko: Ad-hoc Mobile 3D Tracking Using Bluetooth Low Energy and Inaudible Signals for Cross-Device Interaction

3D debug view
each arrow points to the other phone
tracking solely based on stereo sounds
sounds made audible for demonstration

Enough technologies -> here is a fun project

THAW: Hybrid Interactions with Phones on Computer Screens

TEI 2015

Leigh et.al. from MIT

Single user interaction

Multi-user interaction

Sensing beyond interaction

Single user interaction
Multi-user interaction
Sensing beyond interaction

SpiroCall: Measuring Lung Function over a Phone Call

SpiroCall: Measuring Lung Function over a Phone Call

Mayank Goel[1], Elliot Saba[1], Maia Stiber[2], Eric Whitmire[1], Josh Fromm[1],
Eric C. Larson[3], Gaetano Borriello[1], Shwetak N. Patel[1]

[1]Computer Science and Engineering, Electrical Engineering DUB Group University of Washington Seattle, WA 98195

[2]Inglemoor High School Kenmore, WA 98028 mwstiber@gmail.com

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{mayankg, sabae, emwhit, jwfromm, gaetano, shwetak}@uw.edu

ABSTRACT

Cost and accessibility have impeded the adoption of spirometers (devices that measure lung function) outside clinical settings, especially in low-resource environments. Prior work, called SpiroSmart, used a smartphone's built-in microphone as a spirometer. However, individuals in low- or middle-income countries do not typically have access to the latest smartphones. In this paper, we investigate how spirometry can be performed from *any* phone—using the standard telephony voice channel to transmit the sound of the spirometry effort. We also investigate how using a 3D printed vortex whistle can affect the accuracy of common spirometry measures and mitigate usability challenges. Our system, coined SpiroCall, was evaluated with 50 participants against two gold standard medical spirometers. We conclude that SpiroCall has an acceptable mean error with or without a whistle for performing spirometry, and advantages of each are discussed.

Author Keywords
Health sensing; spirometry; mobile phone sensing; signal processing; machine learning.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (*e.g.*, HCI): Miscellaneous.

Figure 1. A user using SpiroCall on a feature phone (Sony w580i) with, and without a SpiroCall whistle.

Recently, a number of health applications have been developed to estimate physiological measures such as heart rate [13], respiratory rate [8,12], pupillary dilation [14], and newborn jaundice [5]. Larson *et al.* [9] introduced

CHI 2016
Goel et.al. from UW

Seismo: Blood Pressure Monitoring using Built-in Smartphone Accelerometer and Camera

Seismo

Blood Pressure Monitoring using Built-in Smartphone Accelerometer and Camera

Edward Jay Wang
Junyi Zhu
Mohit Jain
Tien-Jui Lee
Elliot Saba
Lama Nachman
Shwetak Patel

UNIVERSITY of WASHINGTON ubicomplab intel LABS

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Seismo: Blood Pressure Monitoring using Built-in Smartphone Accelerometer and Camera

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ABSTRACT
Although cost-effective at-home blood pressure monitors are available, a complementary mobile solution can ease the burden of measuring BP at critical points throughout the day. In this work, we developed and evaluated a smartphone-based BP monitoring application called *Seismo*. The technique relies on measuring the time between the opening of the aortic valve and the pulse later reaching a periphery arterial site. It uses the smartphone's accelerometer to measure the vibration caused by the heart valve movements and the smartphone's camera to measure the pulse at the fingertip. The system was evaluated in a nine participant longitudinal BP perturbation study. Each participant participated in four sessions that involved stationary biking at multiple intensities. The Pearson correlation coefficient of the blood pressure estimation across participants is 0.20-0.77 (μ=0.55, σ=0.19), with an RMSE of 3.3-9.2 mmHg (μ=5.2, σ=2.0).

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous; I.5.4. Image Processing and Computer Vision: Applications

Author Keywords
Physiological sensing; noninvasive blood pressure; pulse transit time; photoplethysmography; seismocardiography; PTT; PPG; SCG

Figure 1. Measuring blood pressure using Seismo, a smartphone application that uses the built-in accelerometer and camera to calculate pulse transit time.

hypertension and effectiveness of treatments over infrequent in-clinic monitoring [1]. Currently, at home monitoring of BP relies on automated oscillometry-based BP arm cuffs for daily measurements. Although this way of automated way of measuring blood pressure enable out of clinic monitoring, they are cumbersome and inconvenient [20, 19].Due to these drawbacks, patients typically only perform arm cuff-based measurements once a day, and thus cannot capture the fluctuations in BP that occurs throughout the day due to exercise, activities, and other stressors.

Advances in mobile technologies now present an opportunity to have always available health monitoring capabilities as more and more people carry a smartphone around with them.

CHI 2018
Wang et.al. from UW

Single user interaction
Multi-user interaction
Sensing beyond interaction
Beyond sensing

MobiLimb

Augmenting Mobile Devices with a Robotic Limb

MobiLimb: Augmenting Mobile Devices with a Robotic Limb *Marc Teyssier, Gilles Bailly, Catherine Pelachaud, Eric Lecolinet* **UIST 18**

Recap

Recap

Speakers

TrueDepth (RGB-D) Sensor

Accelerometer
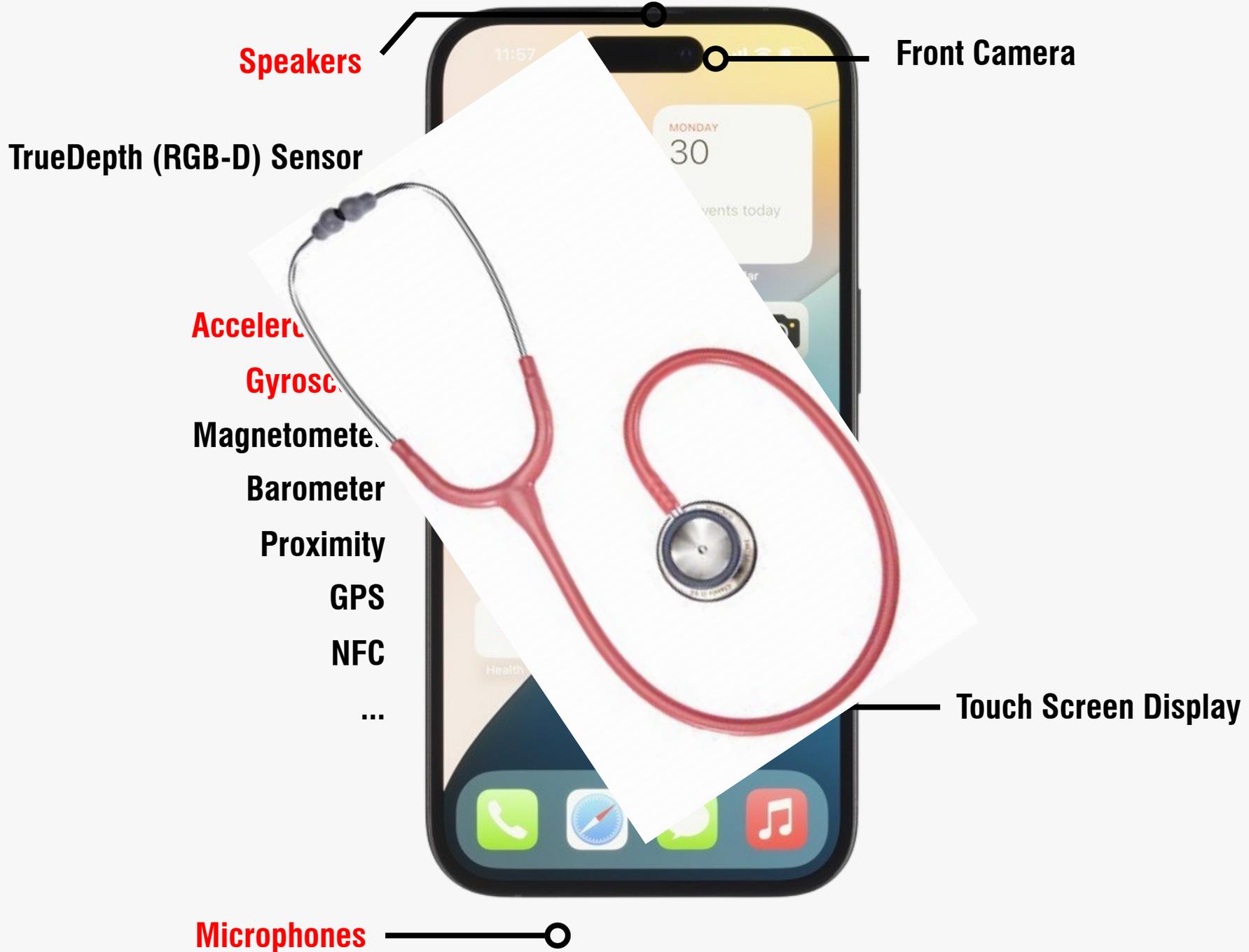
Gyroscope

Magnetometer

Barometer

Proximity

GPS

NFC

...

Front Camera

Touch Screen Display

Microphones

Recap

Speakers

Front Camera

TrueDepth (RGB-D) Sensor

Accelero...

Gyrosco...

Magnetometer

Barometer

Proximity

GPS

NFC

...

Touch Screen Display

Microphones

Optional readings

CHI 2019

Wang et.al.

UIST 2013

Yang et.al.