Device-free tracking

Doppler radar effect

Limitations of Doppler

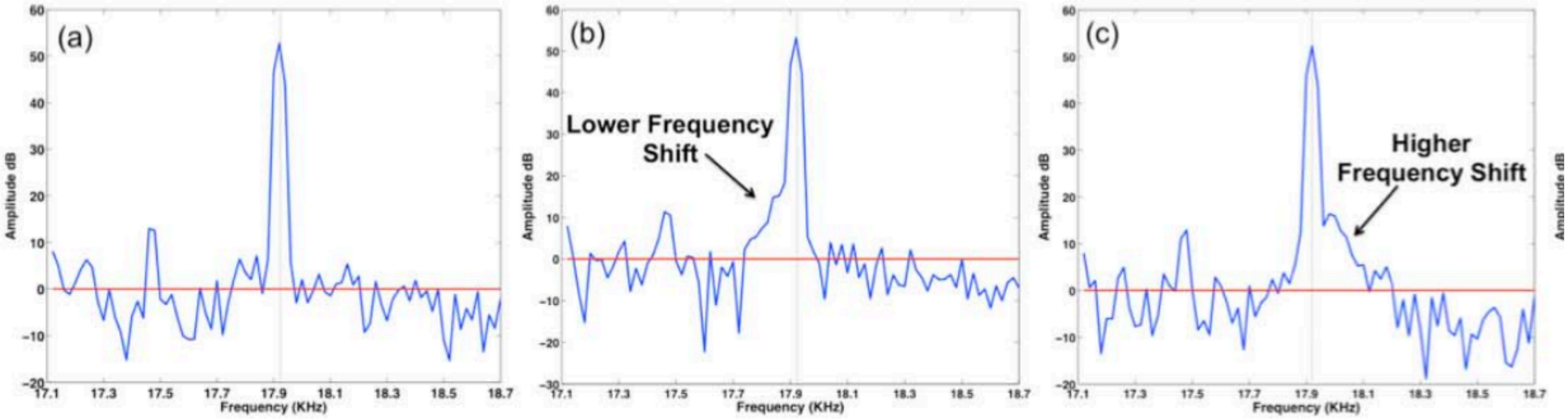
Algorithms to get better resolution

SoundWave

- Transmit 18-20 kHz signals from laptop speaker
- Capture reflections on the laptop microphone at 48 kHz sampling rate
- Perform a 4800 point FFT over a sliding window

$$f_r = f_t \cdot \left(\frac{c+v}{c-v}\right)$$

$where,\ f_r = perceived\ frequency\ at\ microphone;$
$f_t = original\ frequency\ from\ speaker;$
$c = speed\ of\ sound\ in\ air;$
$v = velocity\ of\ target/hand$



Doppler radar effect

Limitations of Doppler

Algorithms to get better resolution

DFT (Discrete Fourier Transform)

$$X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-\frac{i2\pi}{N}kn}$$

$$= \sum_{n=0}^{N-1} x_n \cdot \left[\cos\left(\frac{2\pi}{N}kn\right) - i \cdot \sin\left(\frac{2\pi}{N}kn\right)\right]$$

DFT properties

Sampling frequency = f_s (i.e., f_s samples per second)

Slowest frequency ($\frac{2\pi}{N}$ radians per step) = N samples per rotation

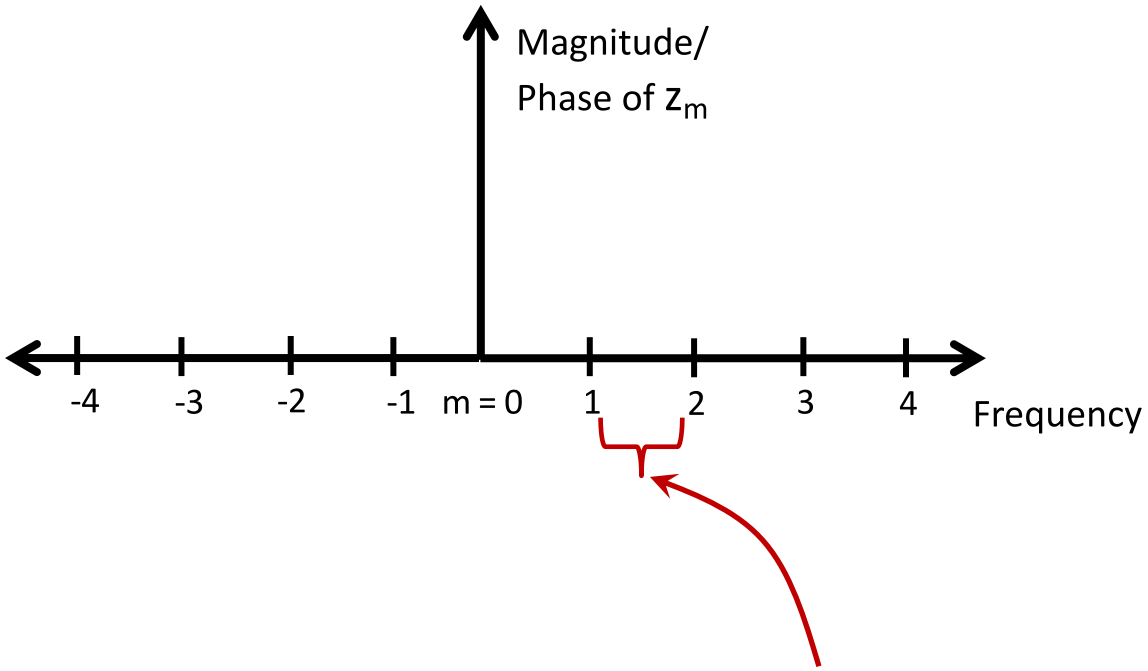
= (N/ f_s) seconds per rotation

Therefore, the slowest frequency = (f_s /N) Hz

Higher frequencies are integer multiple of (f_s /N) Hz

$$0, \frac{f_s}{N}, \frac{2f_s}{N}, \frac{3f_s}{N}, \frac{4f_s}{N}, \dots,$$

The resolution and the highest frequency



Resolution
= minimum observable frequency difference = $\frac{f_s}{N}$

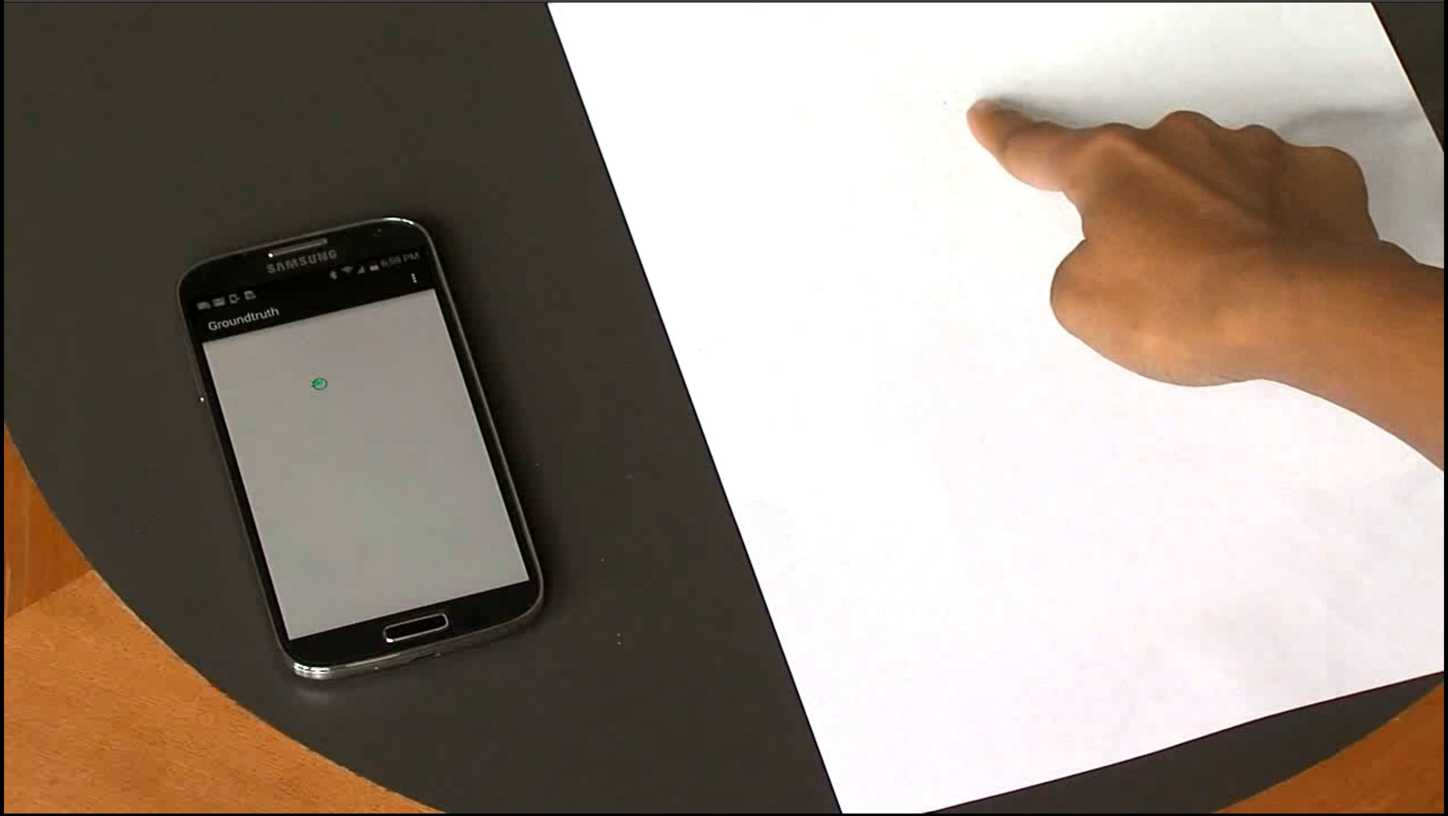
What if the actual frequency falls in between two frequency bins?

FingerIO: Using Active Sonar for Fine Grained Finger Tracking

Rajalakshmi Nandakumar, Vikram Iyer
Shyam Gollakota, Desney Tan

Can we achieve finger tracking for near device interaction with no finger instrumentation and no line of sight?

Application 1: Make anything an input surface



Application 2: Move beyond tiny screens

Application 3: Interaction with occlusions

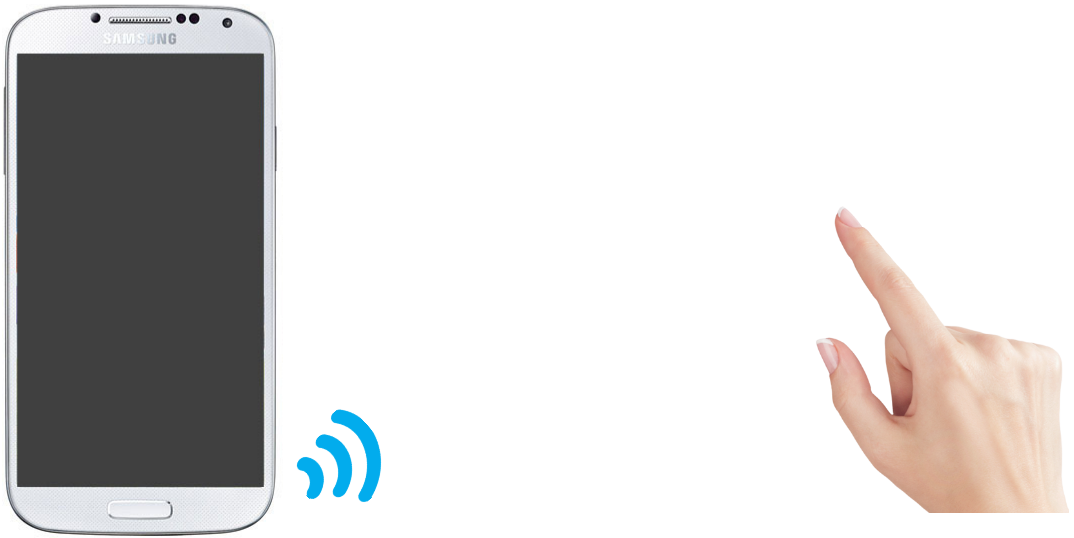
FingerIO

- Track a finger with no instrumentation and no line of sight
- Introduce algorithms and techniques for active sonar without custom hardware
- Achieve 0.8 —1.2 cm accuracy on a Galaxy S4 and smartwatch prototype

Challenges

1) Transform mobile devices into active sonar systems
2) Achieve sub-centimeter level tracking accuracy

Key Idea: Transform the Device into Active Sonar



Sound waves transmitted by the phone speaker reflect off of the finger

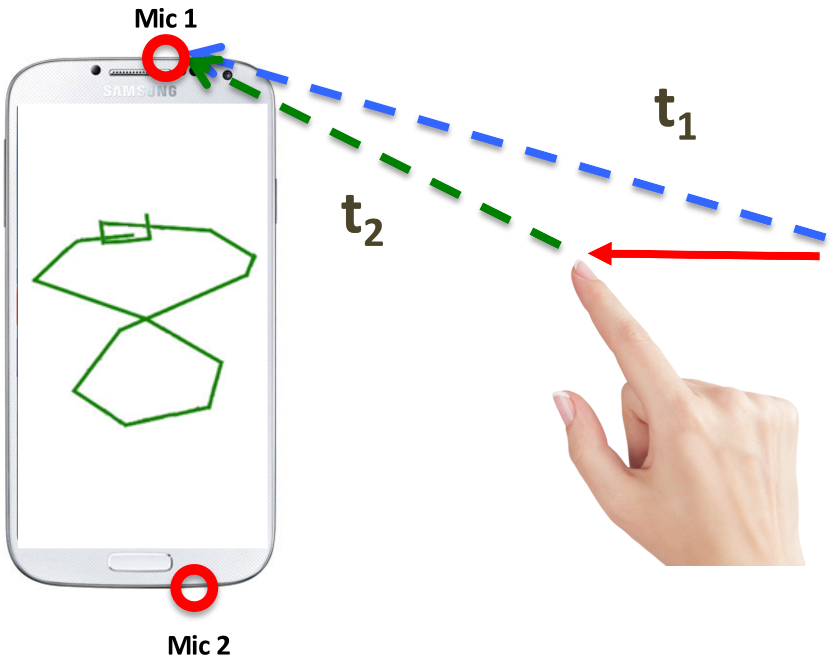
Key Idea: Transform the Device into Active Sonar

Echo from finger is recorded by 2 microphones

Key Idea: Transform the Device into Active Sonar

Time for the echo to arrive back at the phone changes as the finger moves

Accuracy Depends on Time Measurement



Sampling at 48kHz, 1 sample → 0.7cm

Challenges

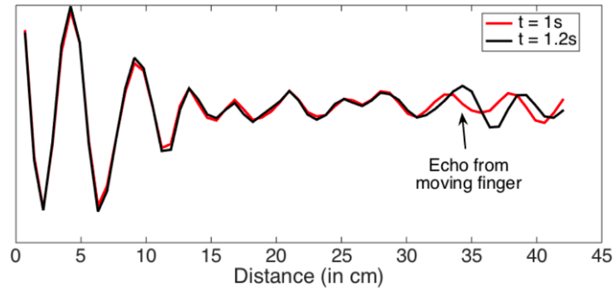
1) Transform mobile devices into active sonar systems

2) Achieve sub-centimeter tracking accuracy

How can we measure arrival time?

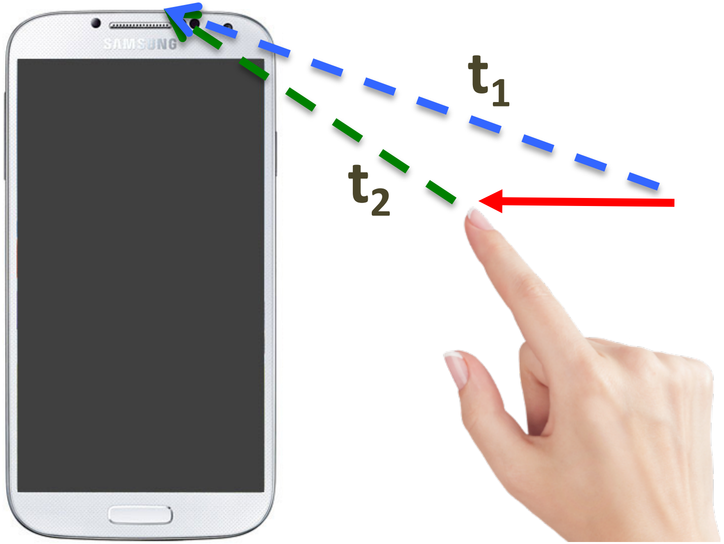
Chirp

Correlation Profile

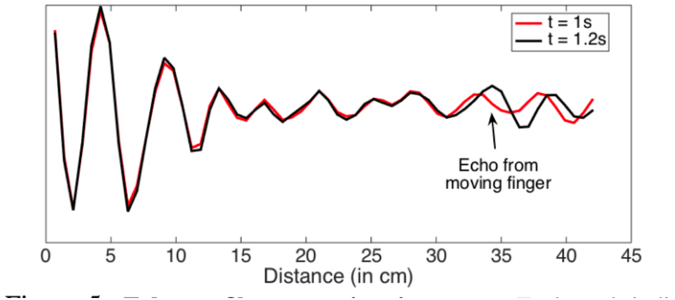


Transmit chirp signals and use autocorrelation to determine arrival times

First Order Solution: Correlation



Correlation Profile



We use the closest moving echo to achieve finger tracking

Correlation in Practice

Estimate echo arrival with 2-3 sample error
→ tracking accuracy of 3 cm

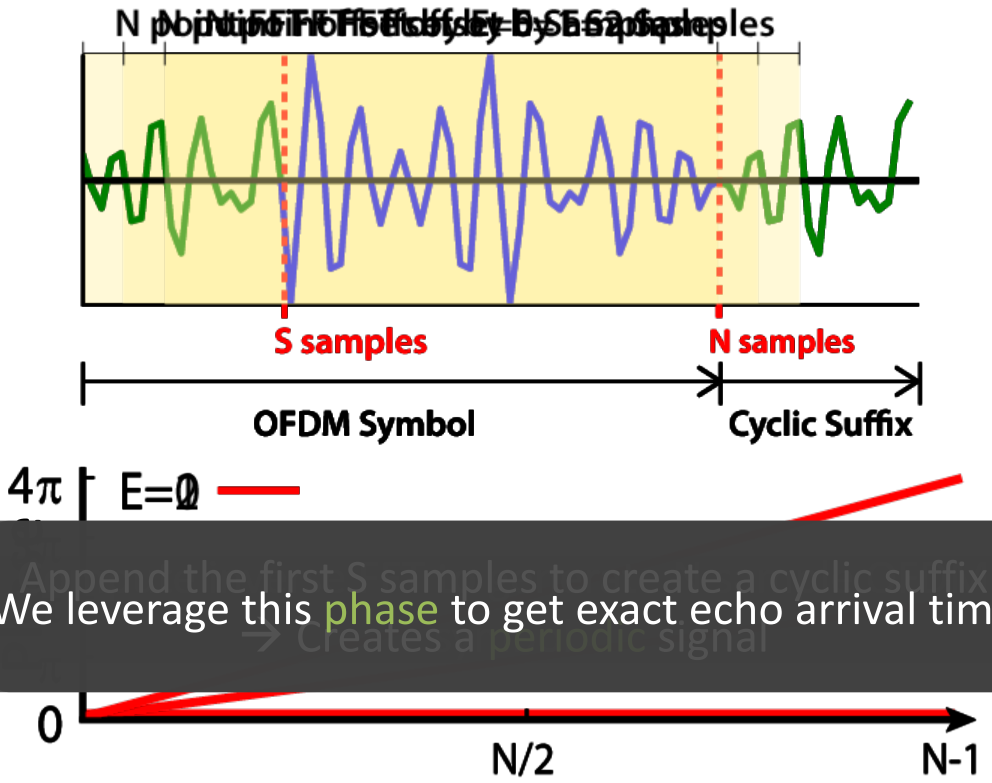
How to get the exact arrival time of the echoes?

Inspiration from WiFi Networks

- Transmitters and receivers do not share a common, synchronized clock
- Receivers need to determine the start of a message to successfully decode

WiFi's Solution: OFDM

Timing Errors Create FFT Phase Offsets

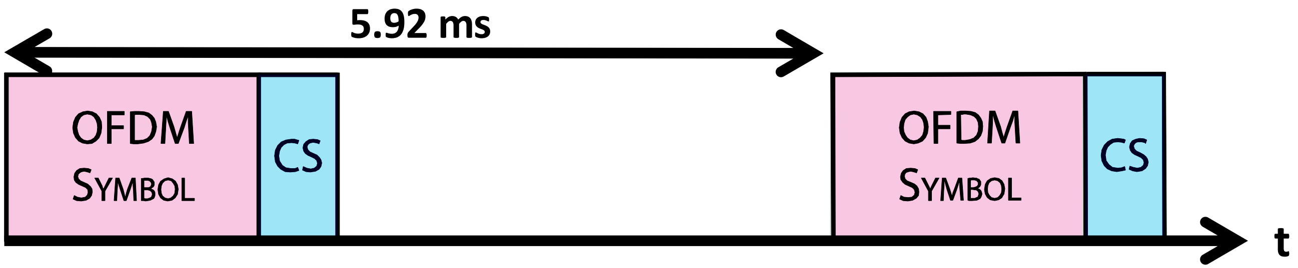


Append the first S samples to create a cyclic suffix

→ Creates a periodic signal

We leverage this phase to get exact echo arrival time

Putting it All Together



1. Transmit 18-20 kHz OFDM symbols every 5.92 ms
2. Use correlation to get a coarse timing estimate within 2-3 samples
3. Correct error using phase properties of OFDM to achieve < 1 cm accuracy

Evaluation

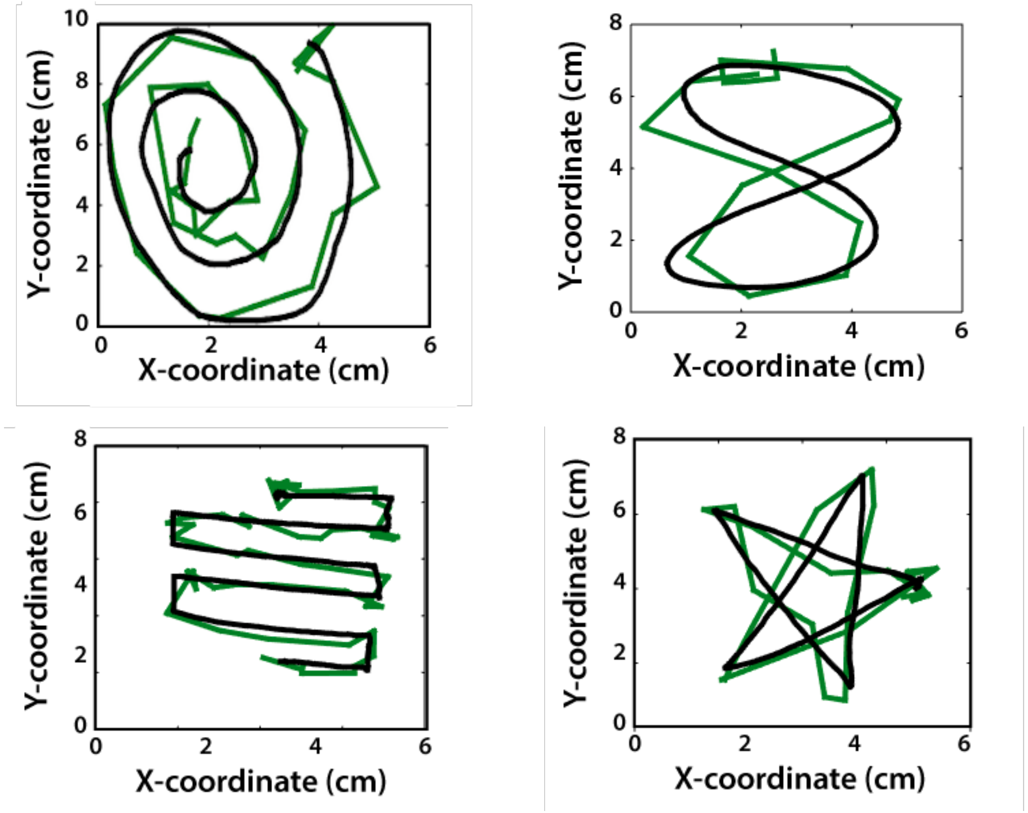
How accurate is FingerIO?

Random user drawings
10 Users
3 Repetitions

30 Total measurements

0.8 cm accuracy
50 x 100 cm^2 around phone

How accurate is FingerIO?

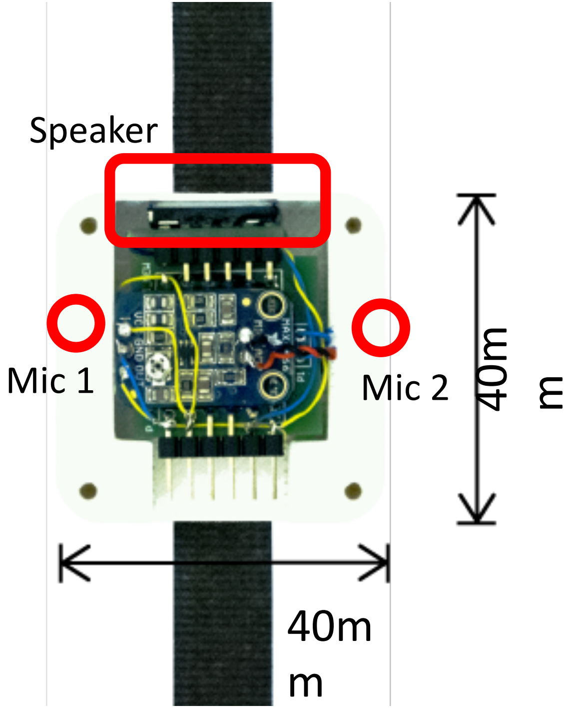


Smartwatch Tracking Accuracy

10 Participants
3 Drawings

30 Total measurements

1.2 cm accuracy
25 x 50 cm^2 on one side



Addressing unintended motion

10 users

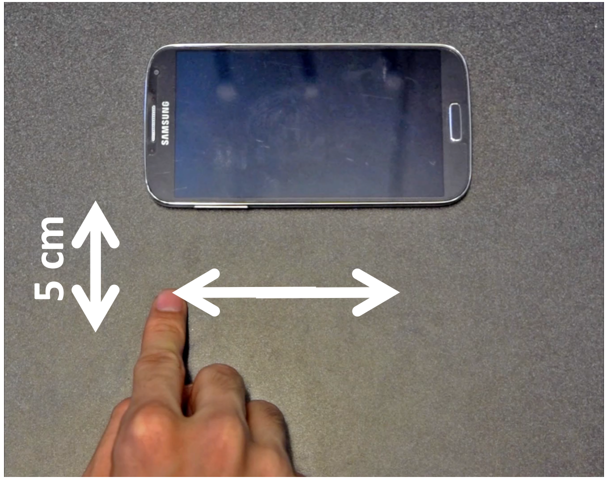
1 min random motion

10 min of motion

0 false detection (watch)

2 false detection (phone)

Start-Stop Gesture



Conclusion

- Track a finger with no instrumentation and no line of sight
- Introduce algorithms and techniques for active sonar without custom hardware
- Enable exciting new directions for finger tracking research