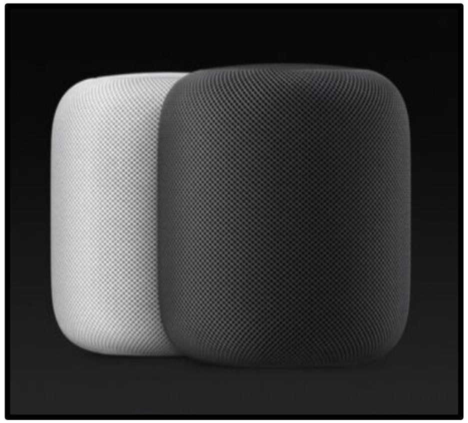
Opportunistic Sensing with Mic Arrays on **Smart Speakers** for **Distal Interaction** and **Exercise Tracking**

Anup Agarwal, **Mohit Jain**, Pratyush Kumar, Shwetak Patel

Smart Speakers

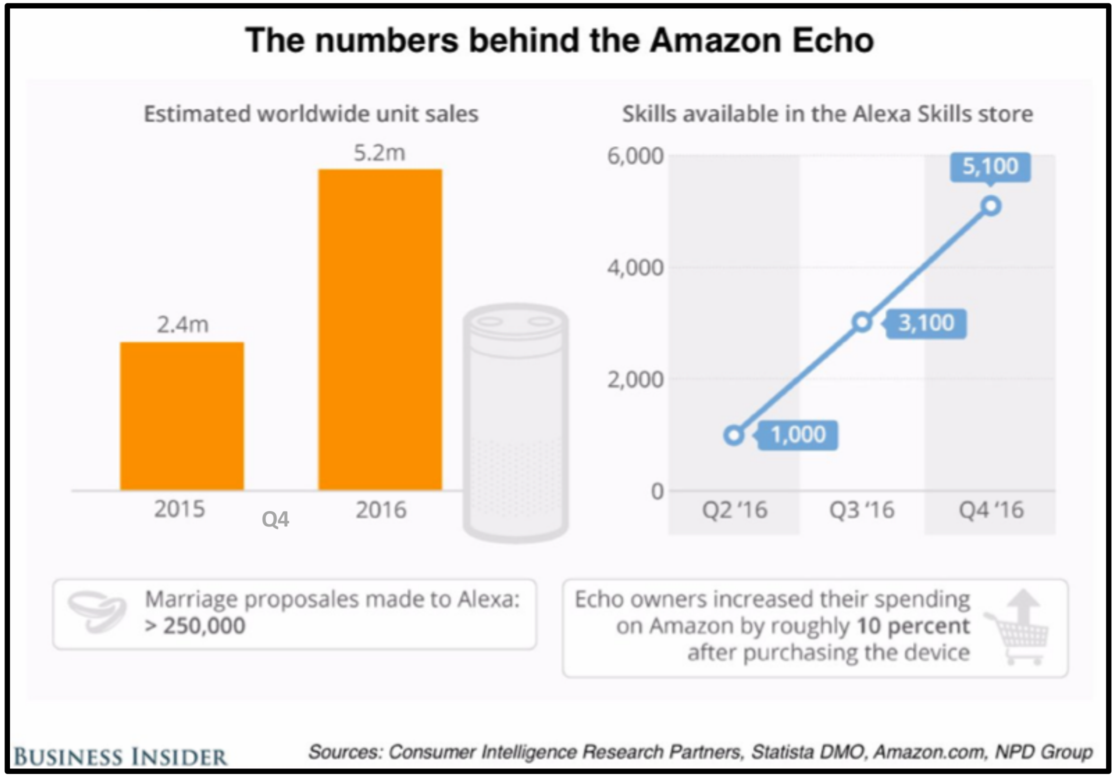
New class of voice-only devices offering hands-free interaction



Smart Speakers

New class of voice-only devices offering hands-free interaction

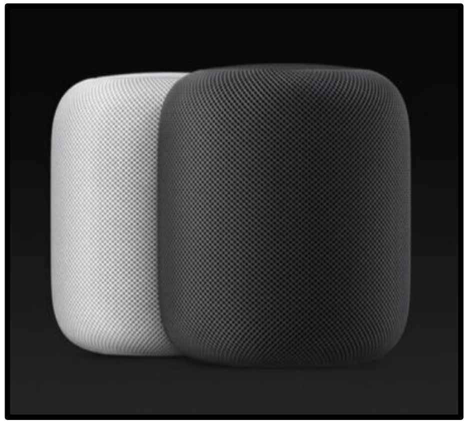
35.6M smart speakers sold in US in 2017, 129% more than 2016



Marriage proposales made to Alexa: **> 250,000**

Echo owners increased their spending on Amazon by roughly **10 percent** after purchasing the device

Sources: Consumer Intelligence Research Partners, Statista DMO, Amazon.com, NPD Group



Smart Speakers

Apple Homepod **6** Sonos One **6** Amazon Echo **7**

To increase the device’s range for recognizing voice commands from across the room using beamforming

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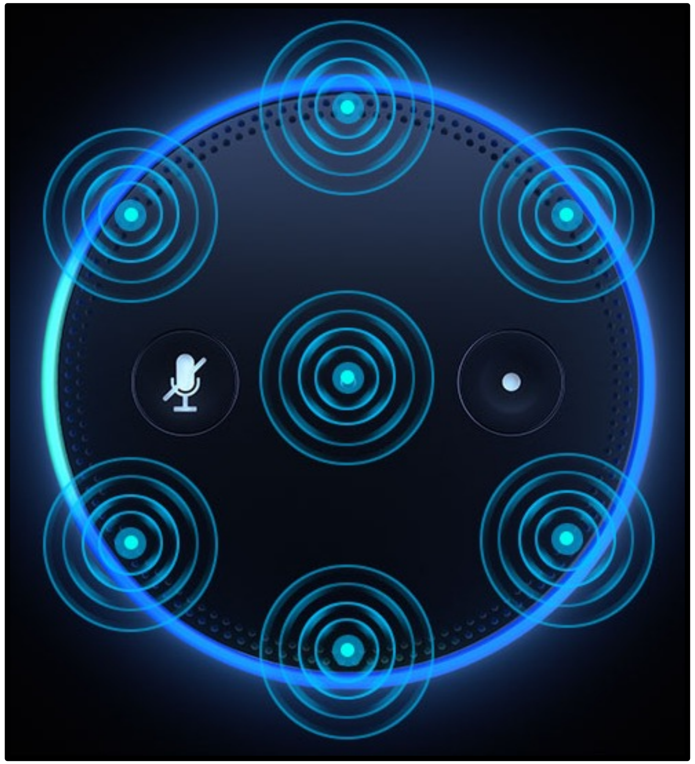
To increase the device's range for recognizing voice commands from across the room using beamforming

Beamforming: The signals from the each mic are combined in a way that signals coming from a certain direction in space interfere constructively while others interfere destructively.

Delay-and-Sum beamforming



Problem

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No notification

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No notification

- User needs to explicitly ask a smart speaker to give notifications.
- The smart speaker detects when a person entered the room, and starts proactive notifications.

Aim

Leverage the mic array in smart speakers for opportunistically sensing gestures

and

classifying and counting exercises

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and

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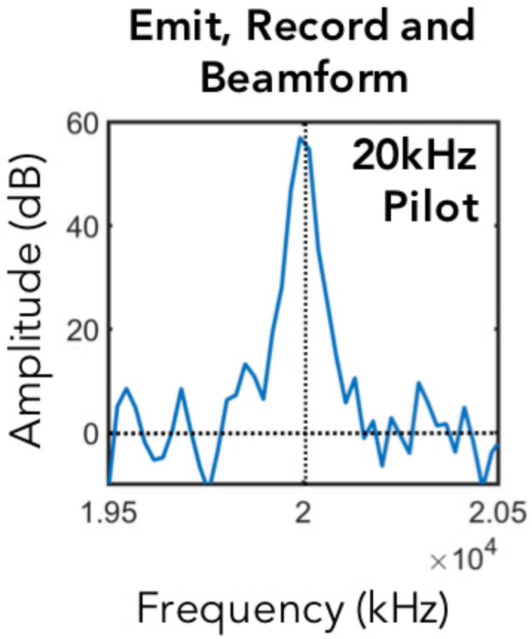
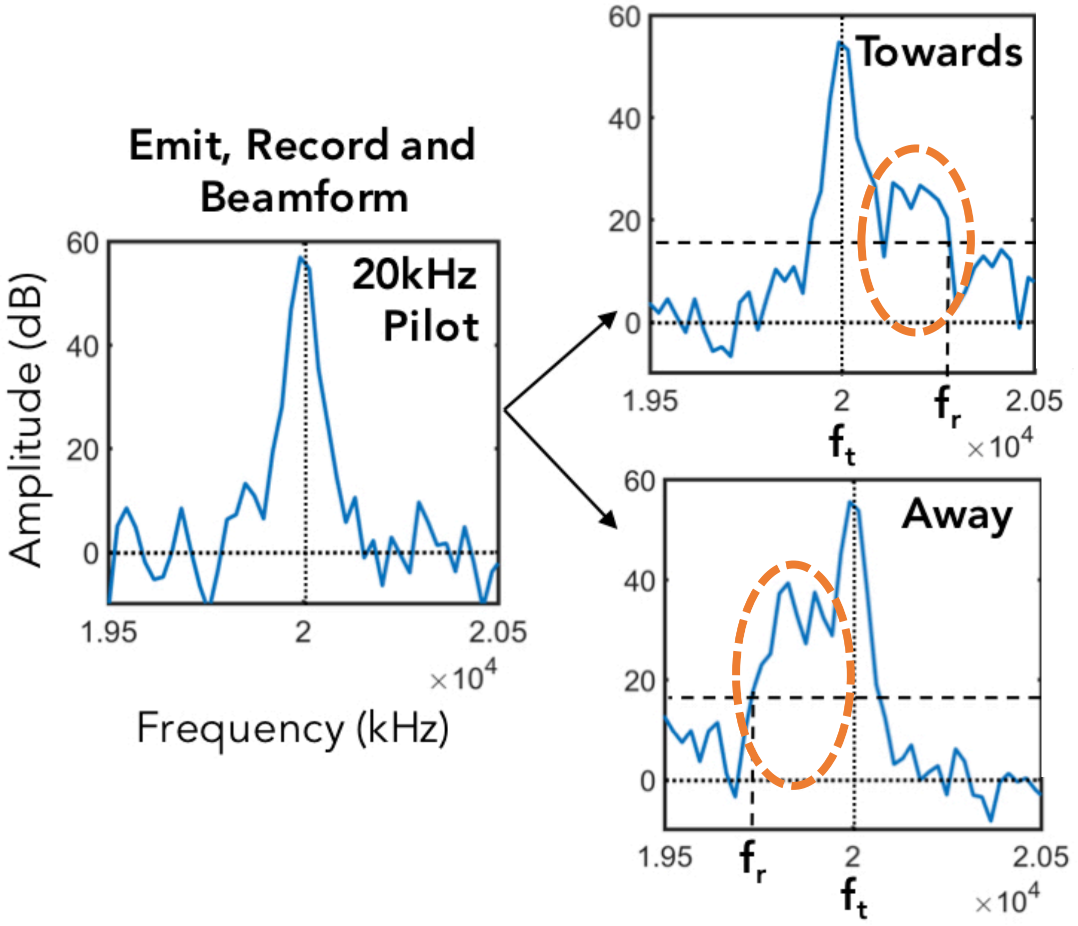
(without speaking aloud)

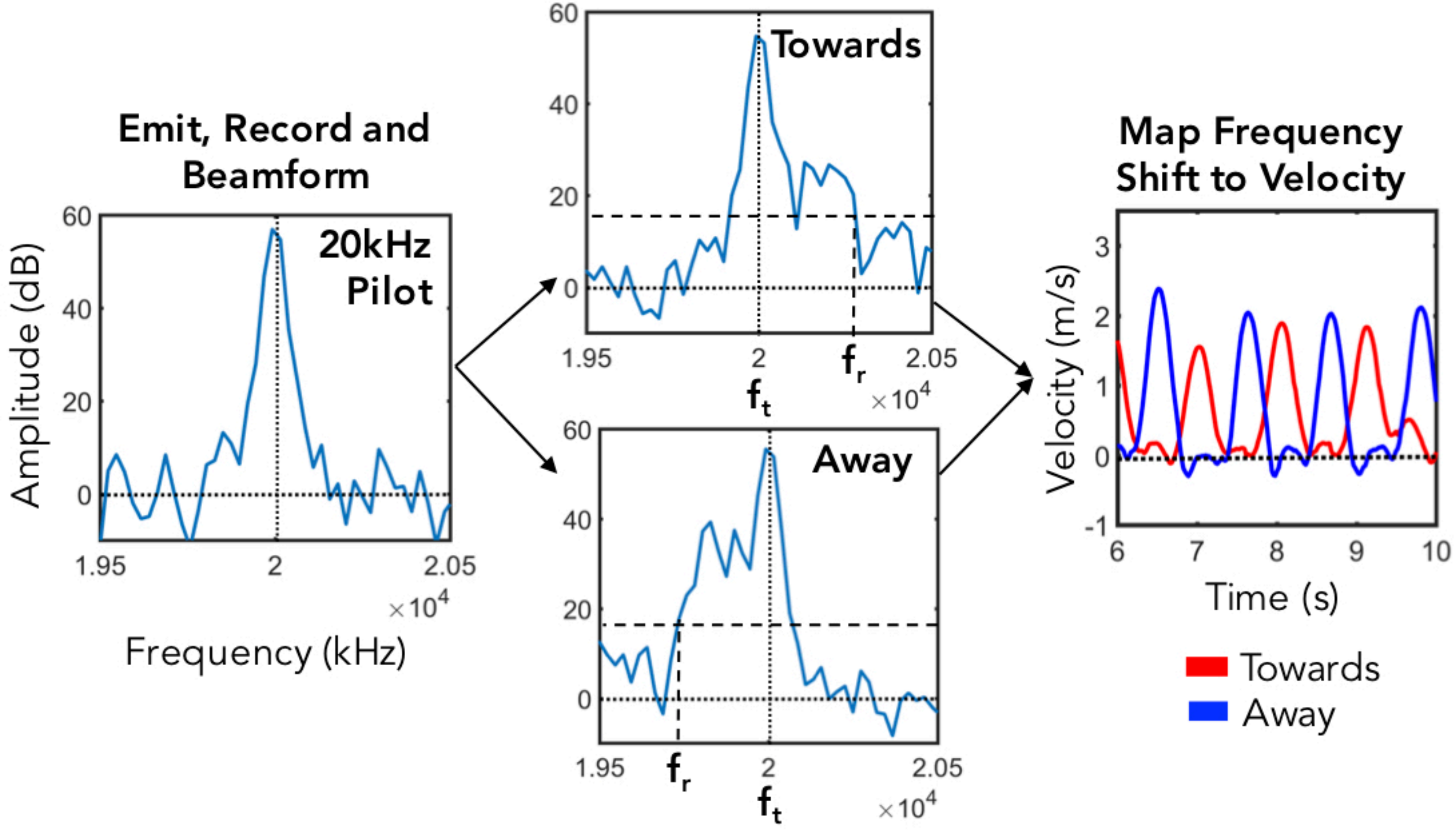
Doppler Shift



Doppler Shift



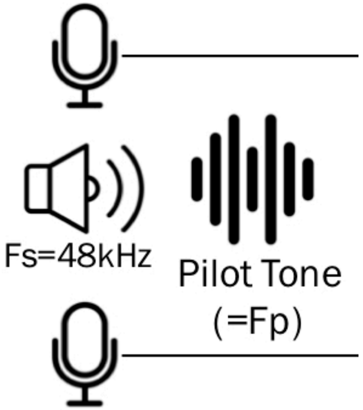
Doppler Shift



Emit, Record and Beamform

Map Frequency Shift to Velocity

System



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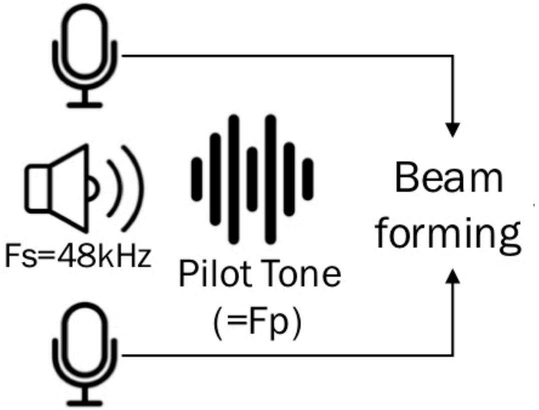

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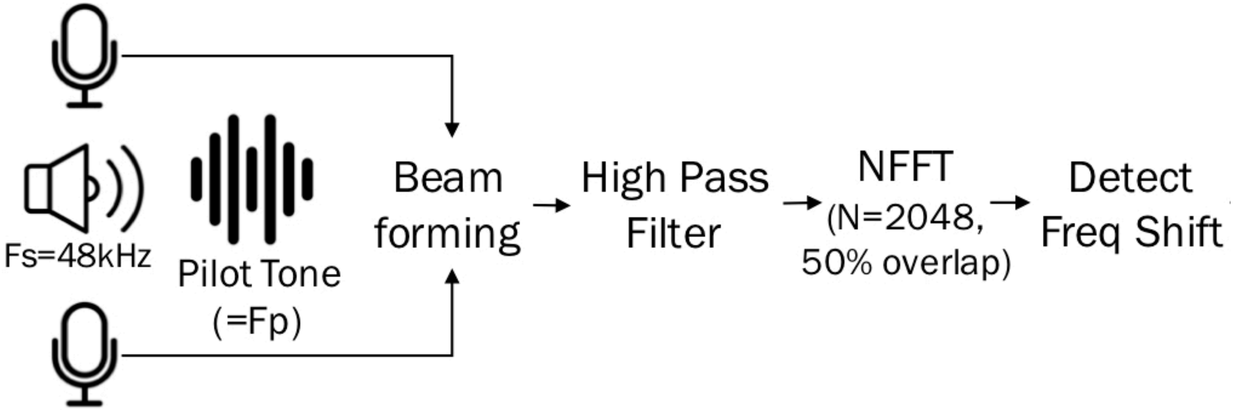
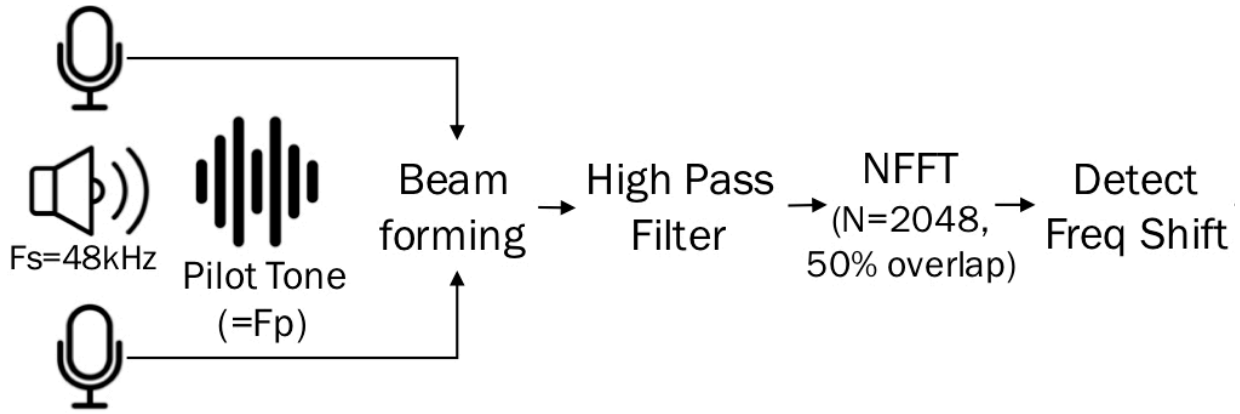

Fs=48kHz
Pilot Tone
(=Fp)
Beam
forming
High Pass
Filter
NFFT
(N=2048,
50% overlap)
Detect
Freq Shift

System



$$f_r = f_t * (c+v)/(c-v)$$

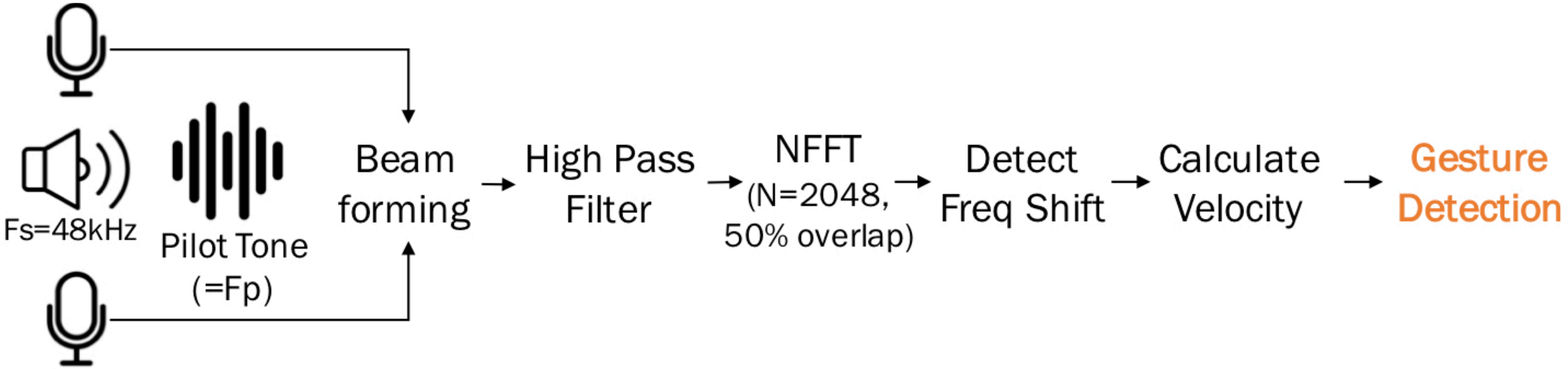
f_r = frequency recorded by mic {farthest from pilot in the interval [f_t-2, f_t+2] kHz above 5dB threshold}

f_t = pilot tone frequency

c = speed of sound in air

v = speed of body movement towards the mic

System


Fs=48kHz
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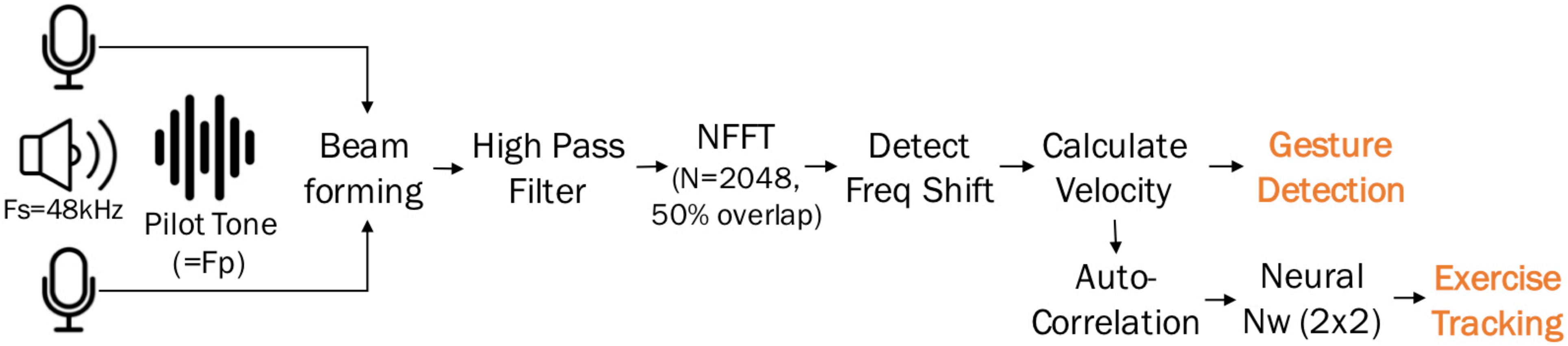
Calculate
Velocity
Gesture
Detection

System



Fs=48kHz

Pilot Tone (=Fp)

Beam forming → High Pass Filter → NFFT (N=2048, 50% overlap) → Detect Freq Shift → Calculate Velocity → **Gesture Detection**

Calculate Velocity → Auto-Correlation → Neural Nw (2x2) → **Exercise Tracking**

veloctiy-time curve
divided into 5s chunks
with 200 ms stride length

Hardware

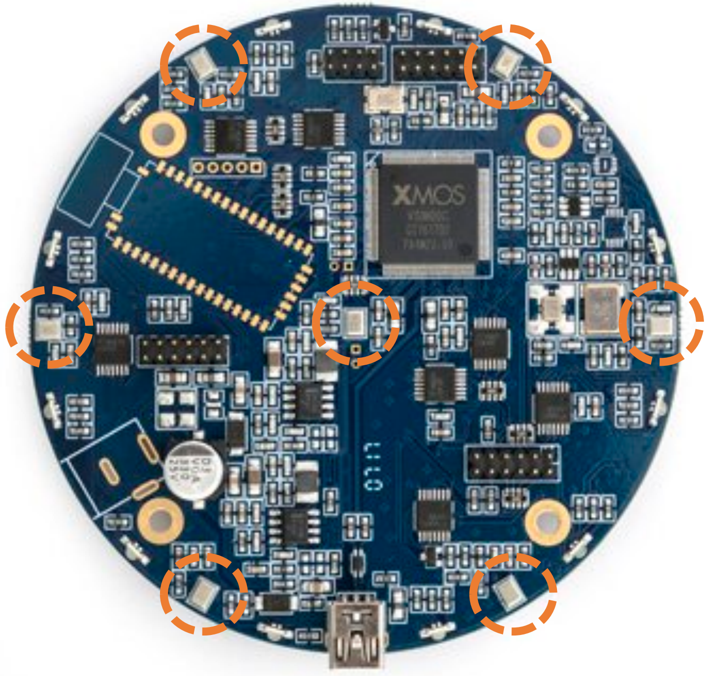
MiniDSP UMA-8 circular USB mic array

7 MEMS microphones

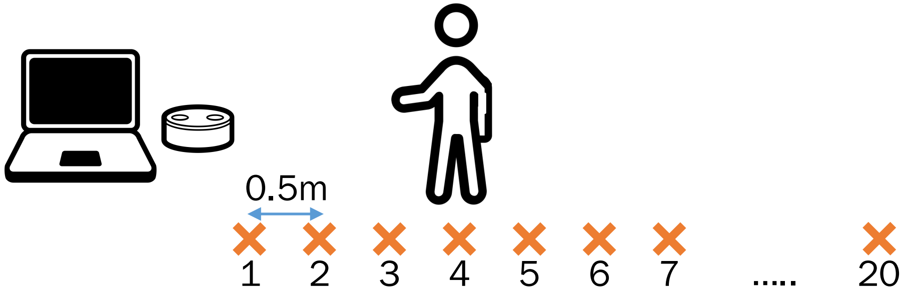
Radius 43 mm

Sampling rate 48kHz (Fs)

Capturing 24 bits per sample



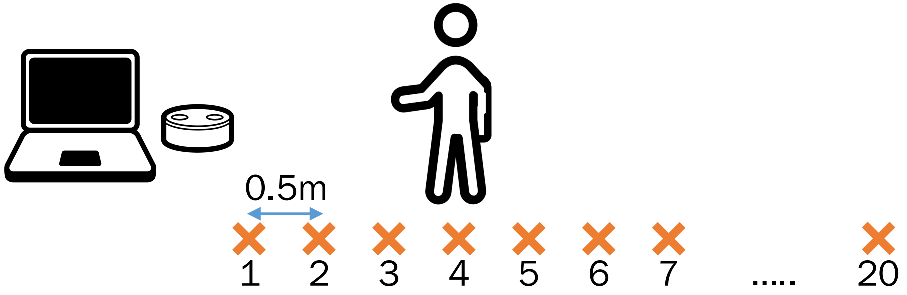
Data Collection: 1



Data Collection: 1

20 markers, 0.5 m away

Forward (pushing hand away from body)
Backward (pulling hand towards the body)



10 times at each marker

Two pilot tones: 20 kHz and 6kHz

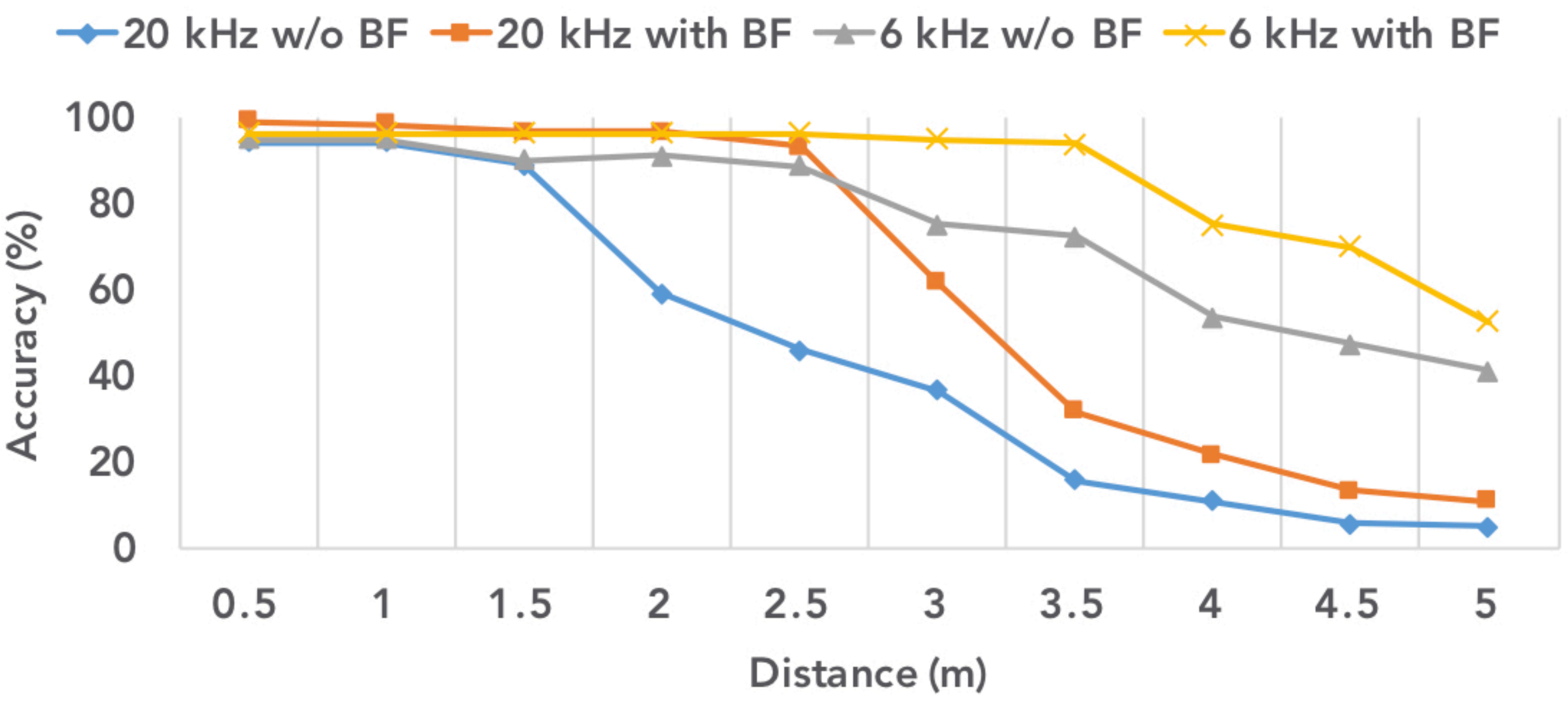
12 participants (10 male, 2 female)

Age = 22.4 ± 4.3 years

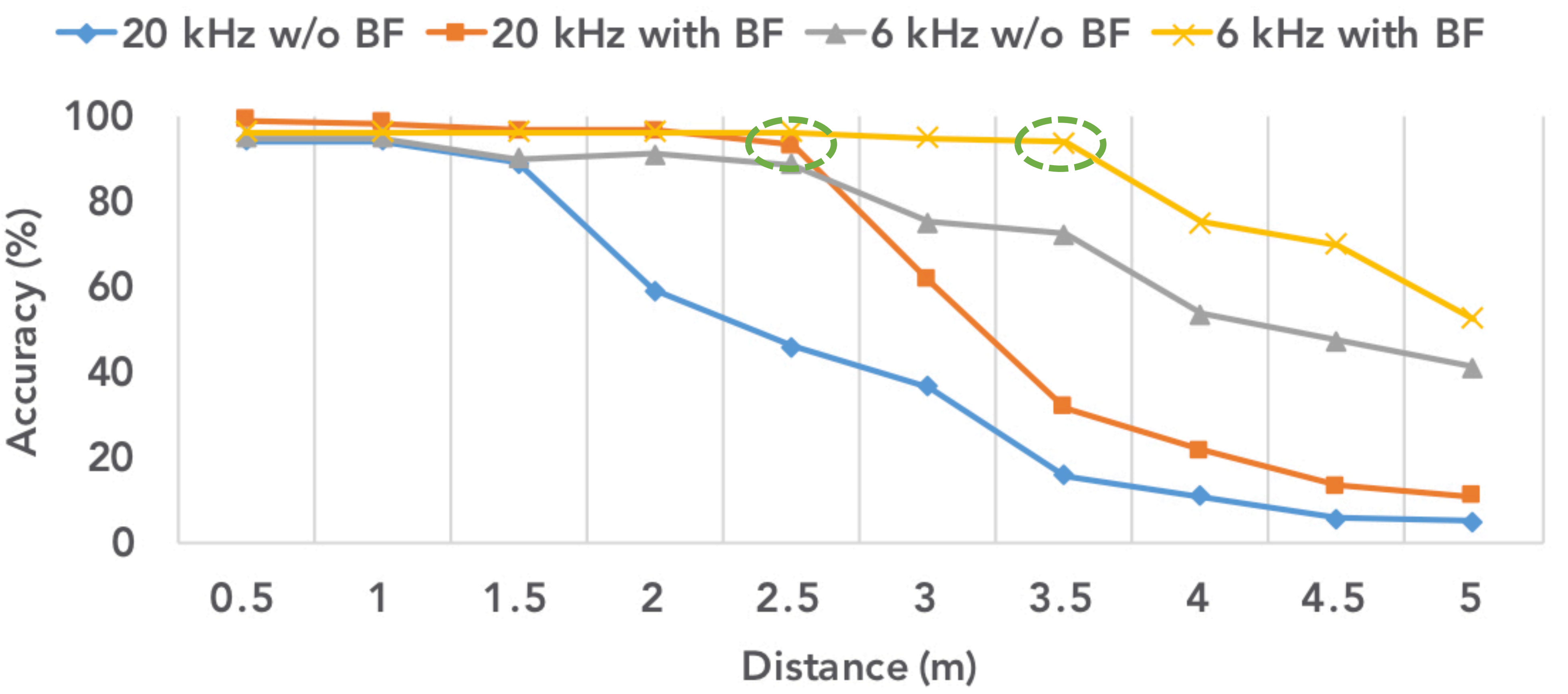
Weight = 73 ± 10.1 kgs

Height = 172.5 ± 8.7 cm

Results: 1


20 kHz w/o BF
20 kHz with BF
6 kHz w/o BF
6 kHz with BF
Accuracy (%)
100
80
60
40
20
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Distance (m)

Results: 1



20 kHz w/o BF
20 kHz with BF
6 kHz w/o BF
6 kHz with BF
100
80
60
40
20
0
Accuracy (%)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Distance (m)

Data Collection: 2

1. Cross stretch

2. Curls

3,4. Folded shoulder rotation (C and AC)

5. On-spot jog

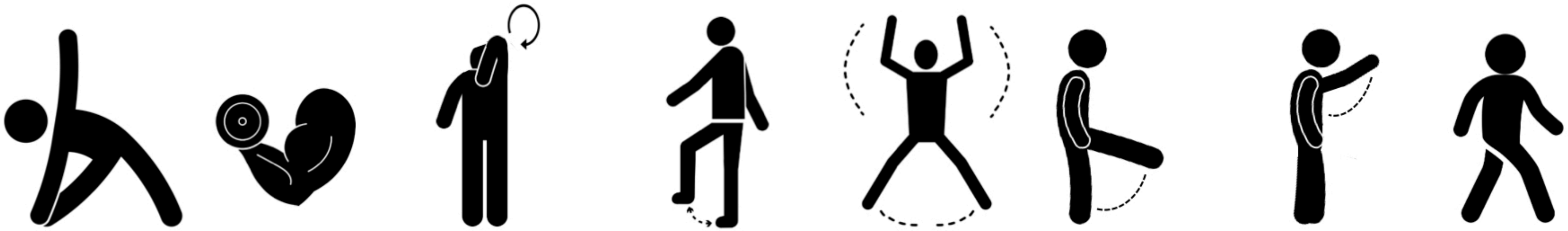
6. Jumping jacks

7. Leg raise

8,9. Shoulder rotation (C and AC)

10. Walk

Data Collection: 2



10 exercises, 20 repetitions each

2.5m from the device

20 kHz pilot tone

17 participants (15 male, 2 female)

Age = 26.4 ± 4.4 years

Weight = 73.6 ± 12.3 kgs

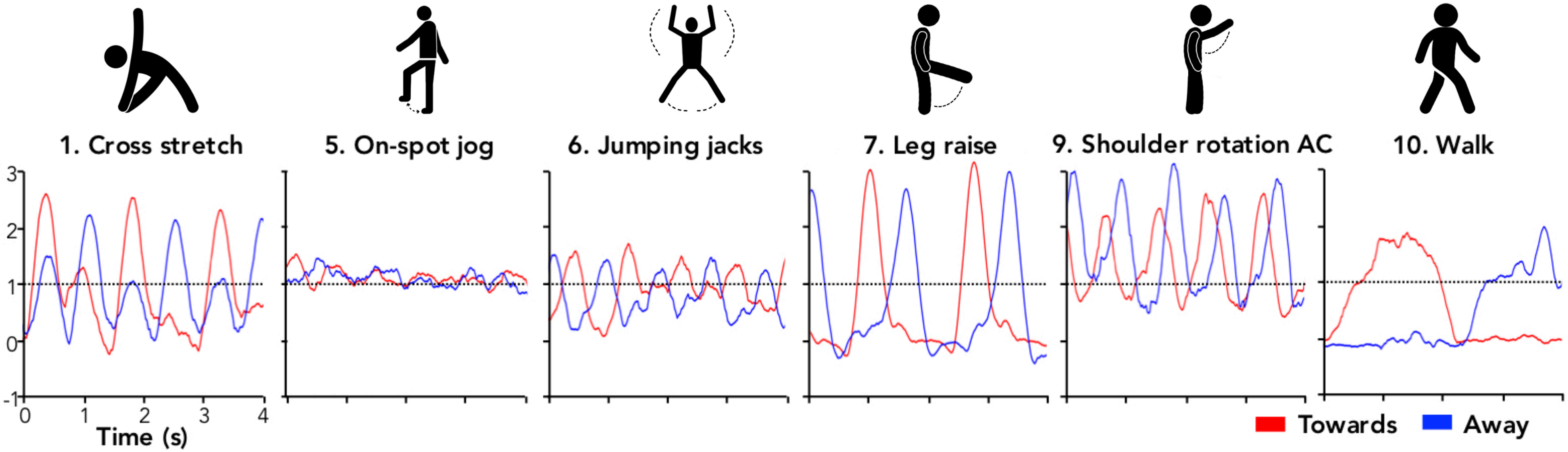
Height = 174 ± 9.6 cms

Average fitness = 3.4 ± 0.8

Daily exercise = 6/17

Exercise 2-3 times a week = 4/17

Results: Exercise Identification



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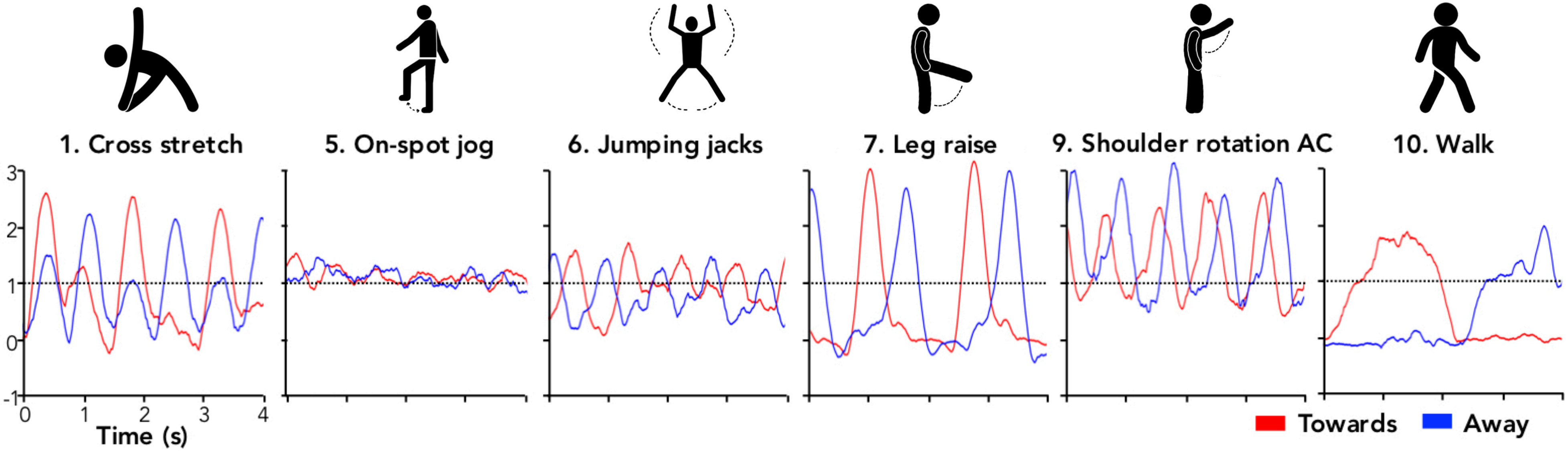

99.8% on the training set

95.9% on the evaluation set

Results: Confusion Matrix

	Predicted Label									
True Label	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Cross stretch	**0.99**	0	0	0	0	0	0	0	0	0
2. Curls	0	**0.99**	0	0	0	0	0	0.01	0	0
3. Folded shoulder rotation C	0	0	**0.93**	0.05	0	0	0	0	0.01	0
4. Folded shoulder rotation AC	0	0.01	0.04	**0.95**	0	0	0	0	0	0
5. On-spot jog	0	0.02	0.02	0.02	**0.87**	0	0.02	0	0	0.04
6. Jumping jacks	0	0	0	0	0	**0.97**	0	0.01	0	0
7. Leg raise	0	0	0	0	0	0	**0.98**	0.02	0	0
8. Shoulder rotation C	0	0.01	0	0	0	0	0.01	**0.97**	0	0.01
9. Shoulder rotation AC	0.01	0.01	0	0	0.01	0.01	0.01	0.04	**0.91**	0
10. Walk	0.02	0.01	0	0	0	0	0	0.02	0.02	**0.93**

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10. Walk

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7. Leg raise	0	0	0	0	0	0	0.98	0.02	0	0
8. Shoulder rotation C	0	0.01	0	0	0	0	0.01	0.97	0	0.01
9. Shoulder rotation AC	0.01	0.01	0	0	0.01	0.01	0.01	0.04	0.91	0
10. Walk	0.02	0.01	0	0	0	0	0	0.02	0.02	0.93

1. Cross stretch

2. Curls

3,4. Folded shoulder rotation (C and AC)

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7. Leg raise

8,9. Shoulder rotation (C and AC)

10. Walk

Results: Exercise Counting

1. Cross stretch

2. Curls
X

3,4. Folded shoulder rotation (C and AC)

5. On-spot jog
X

6. Jumping jacks

7. Leg raise

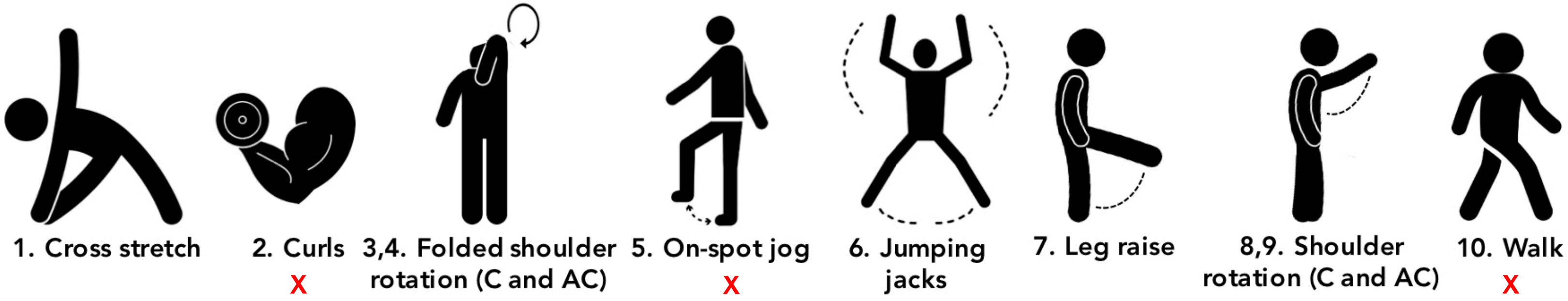
8,9. Shoulder rotation (C and AC)

10. Walk
X

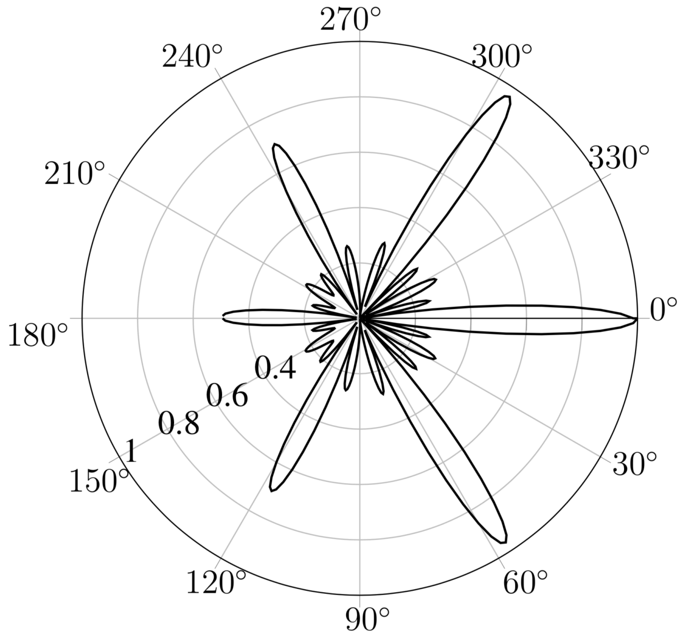
Results: Exercise Counting

	1. Cross Stretch	3. Folded Shoulder Rotation C	4. Folded Shoulder Rotation AC	6. Jumping Jacks	7. Leg Raise	8. Shoulder Rotation C	9. Shoulder Rotation AC
Accuracy (m)	85.7	91.3	94.7	86.7	97.0	95.0	92.2
sd	15.8	16.2	5.1	19.0	4.8	3.7	6.6

91.8% accuracy



Limitations & Future Directions



6 mics
43 mm radius

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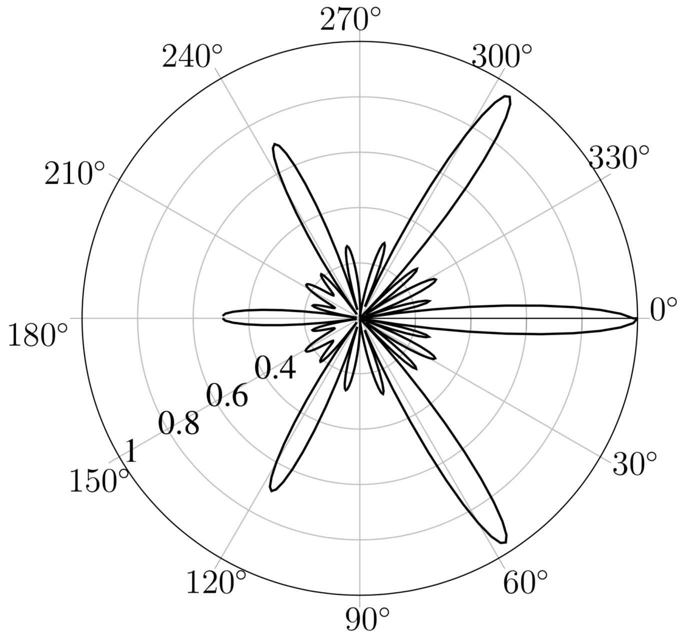

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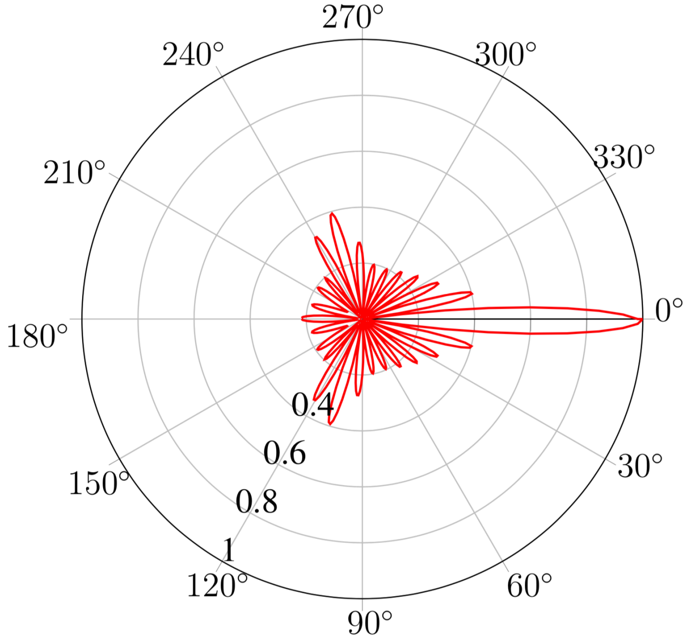
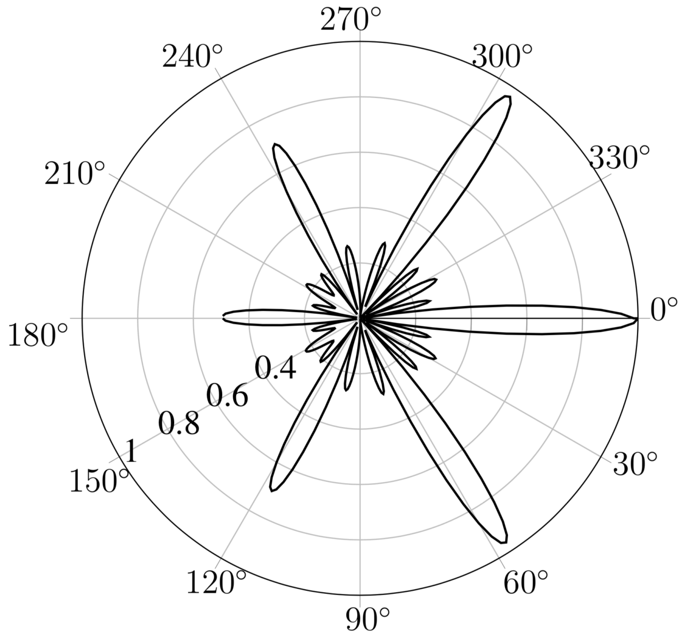


24 mics
43 mm radius

Limitations & Future Directions



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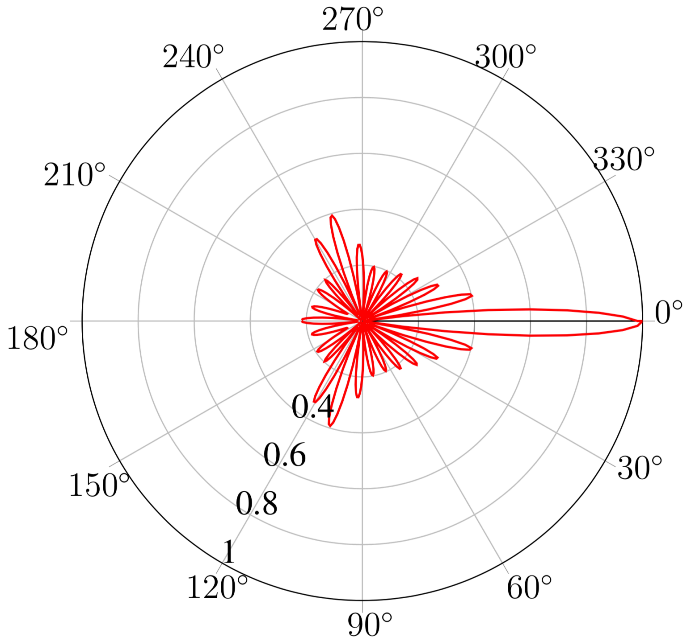

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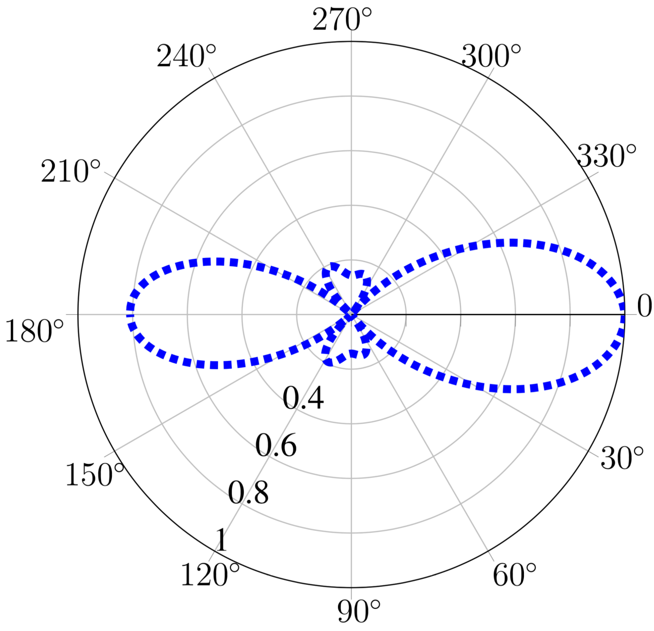

6 mics
8.8 mm radius

Conclusion

Accurately tracking hand movement gestures (96.8%) from a distance of 2.5m

Classifying 10 exercises accurately (96%)

Counting 7 exercises accurately (91.8%)

Thank You!

Mohit Jain

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