mmFlow: Facilitating At-Home Spirometry with 5G Smart Devices

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Respiratory Diseases: A Global Health Challenge

- **Respiratory Diseases:**
  - Asthma
  - Chronic Obstructive Pulmonary Disease (COPD)
  - **COVID-19**

Reduced Lung Function

- Worldwide Cases++:

Asthma	262 M (2019)
COPD	384 M (2019)
COVID-19	178 M (2019-)

- United States Cases++:

Asthma	25 M (2019)
COPD	14.8 M (2019)
COVID-19	33.5 M (2019-)

++ :
WHO: https://www.who.int/health-topics/chronic-respiratory-diseases#tab=tab_1

Spirometry: Lung Function Test

- Spirometry : Common Lung Function Test

Spirometry Setup

Spirometry Procedure

Step 1:
Breathe through your mouth

Step 2:
Full Inhalation

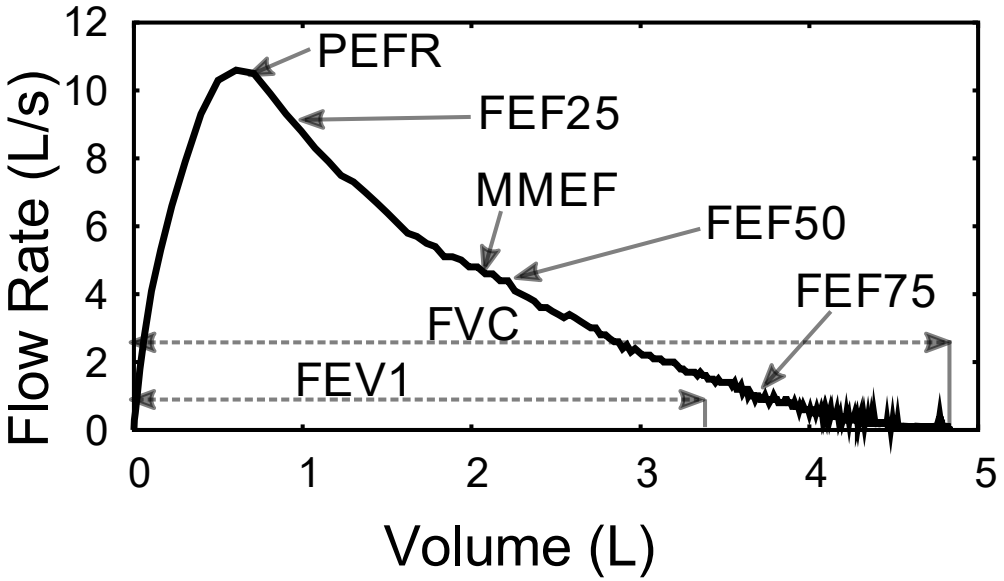
Step 3:
Exhale hard and fast

Step 4:
Exhale until lung is empty

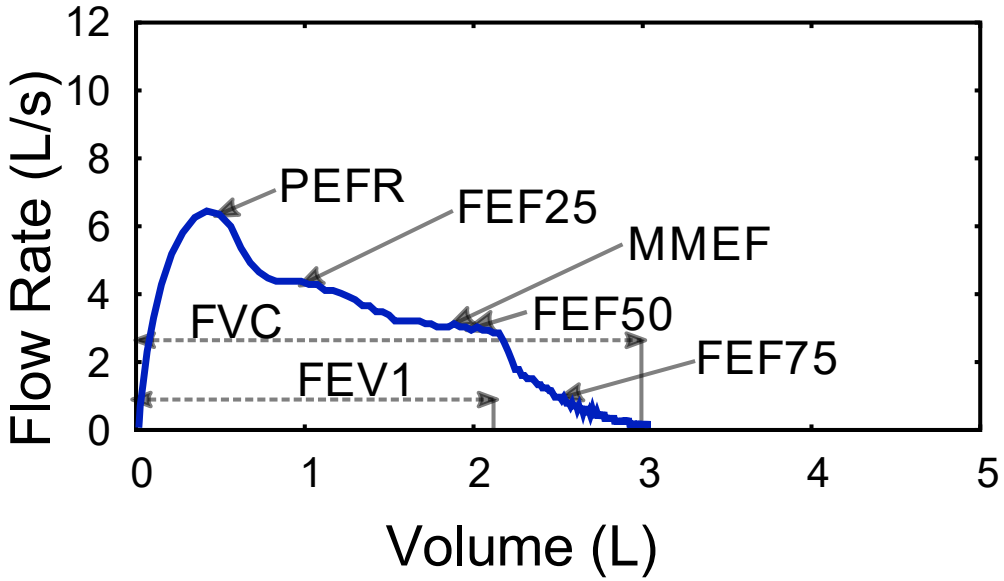
Spirometry: Lung Function Test

Flow – Volume Graph with Lung Function Indicators

Healthy



COPD



Doctors use both lung function indicators and graph to assess the condition

Available Spirometry Solutions

- Daily In-Clinic Spirometers

Bulky

High-Cost

Availability of Doctors

- Portable Spirometers

Accurate but Expensive (>$1200)

Cheap but Error-Prone

- Research Works

Requires Extra Hardware

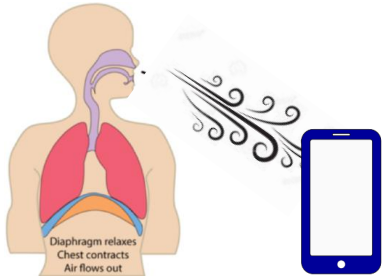
High Hardware Cost

Susceptible to Noise

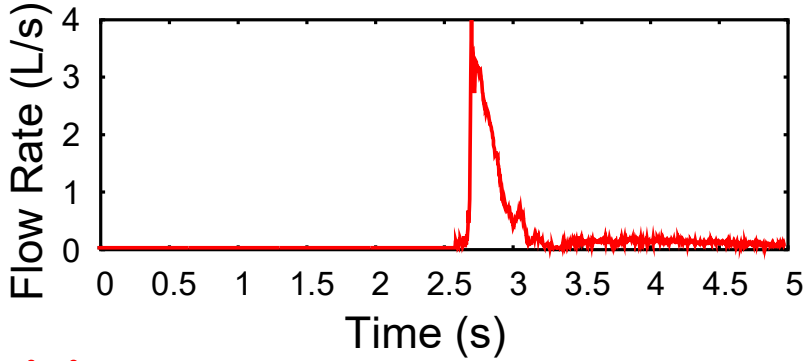
mmFlow Overview

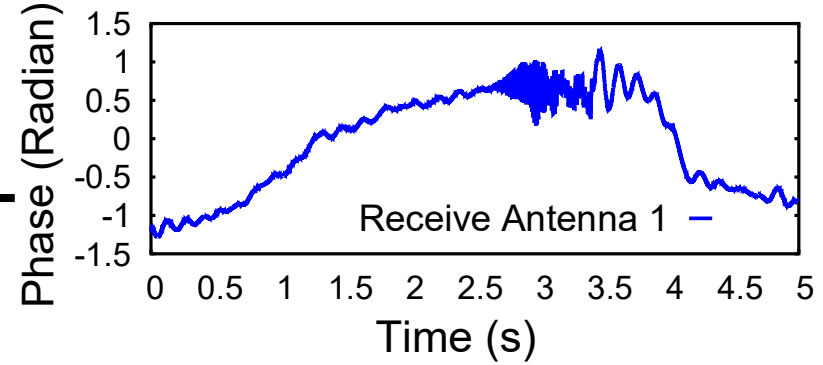
In-Clinic Spirometry

Key Enabling Technology: Millimeter-wave

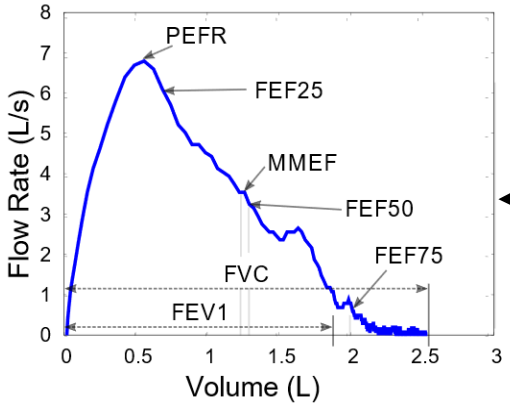


Opportunity: Extremely sensitive to device movement



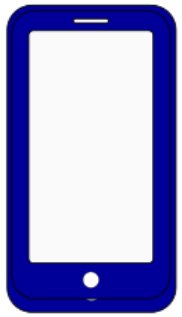


Machine Learning Algorithms



mmFlow: At-Home Spirometry

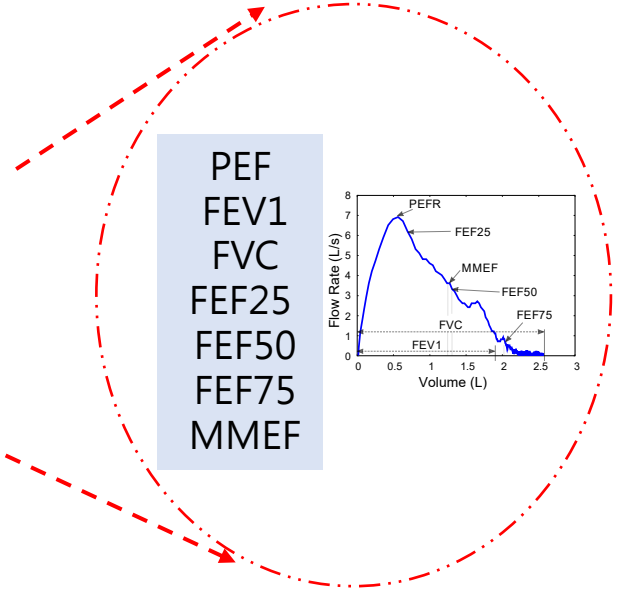
- Utilizes built-in **millimeter-wave technology** in ubiquitous millimeter-wave based mobile devices to perform at home-spirometry



1. Hold a phone in front

2. Inhale

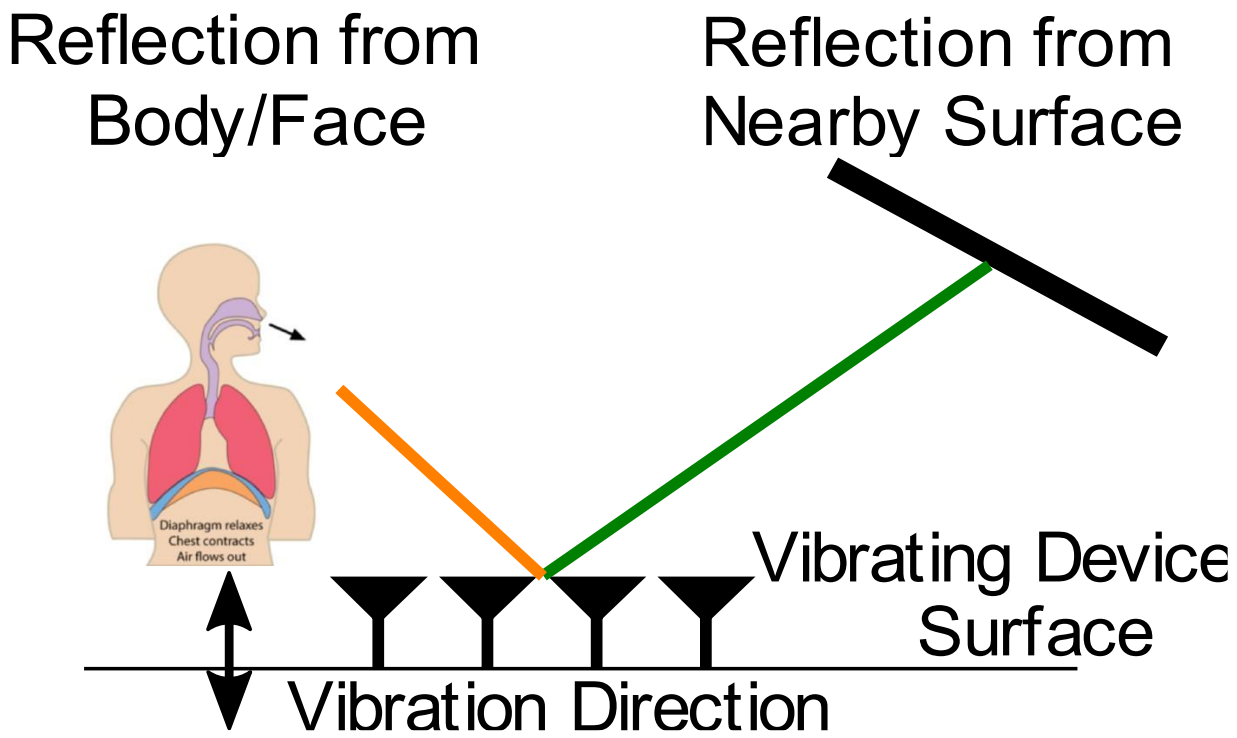
3. Exhale Forcibly



Output

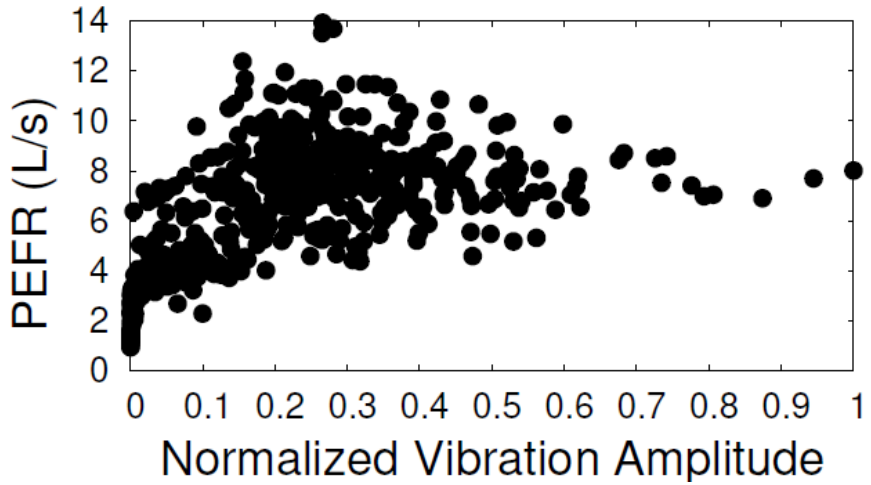
Challenge 1

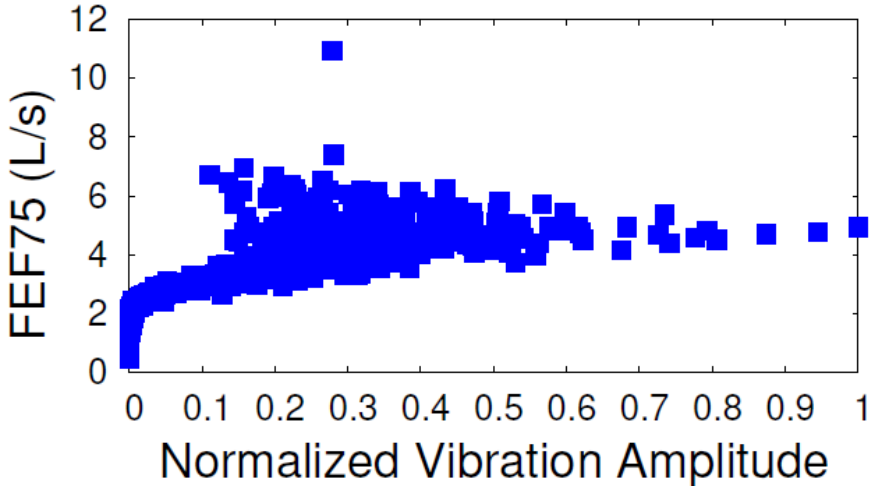
- When user exhales in-front of the 5G mobile device, phase change should only be from airflow vibrations

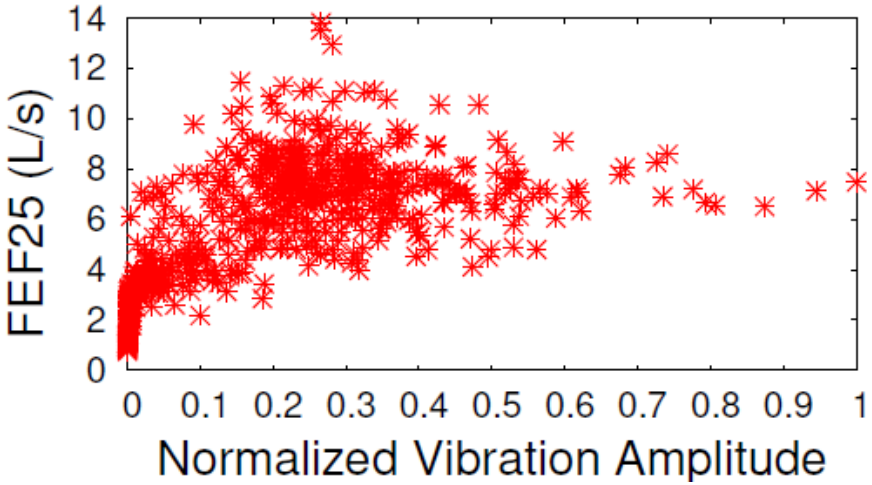


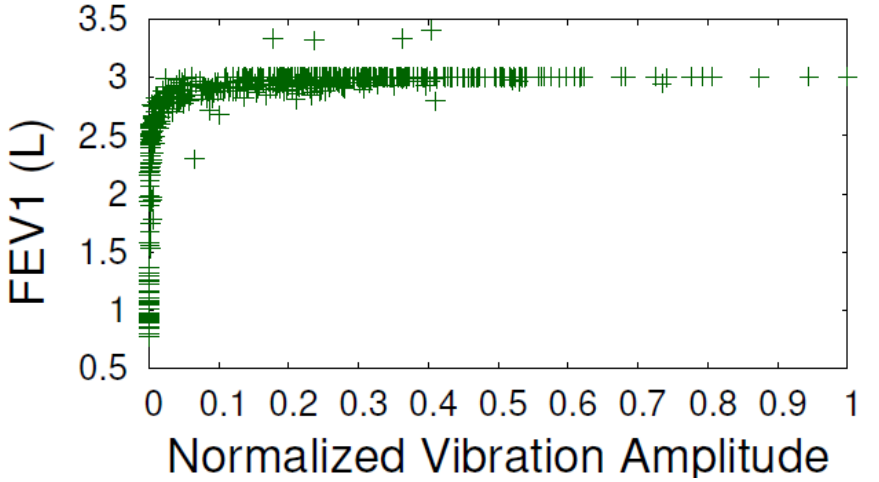
Challenge 2

- Predicting lung function from vibration signal requires modeling non-linear relationship



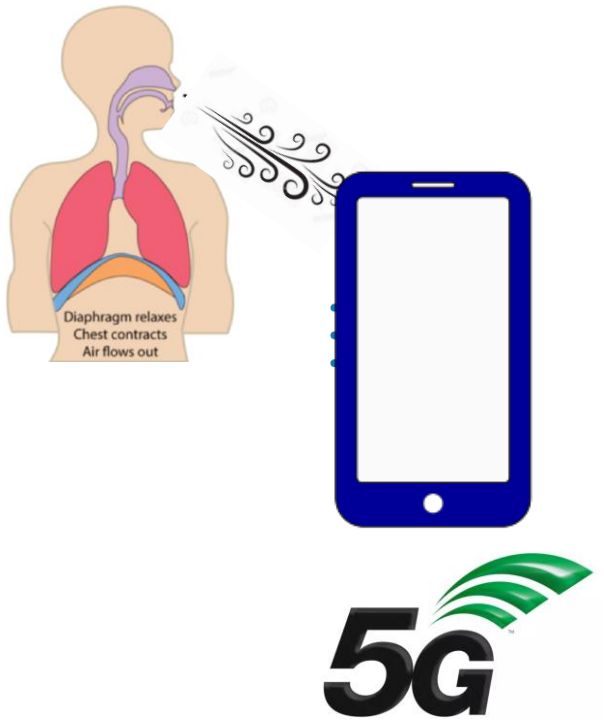




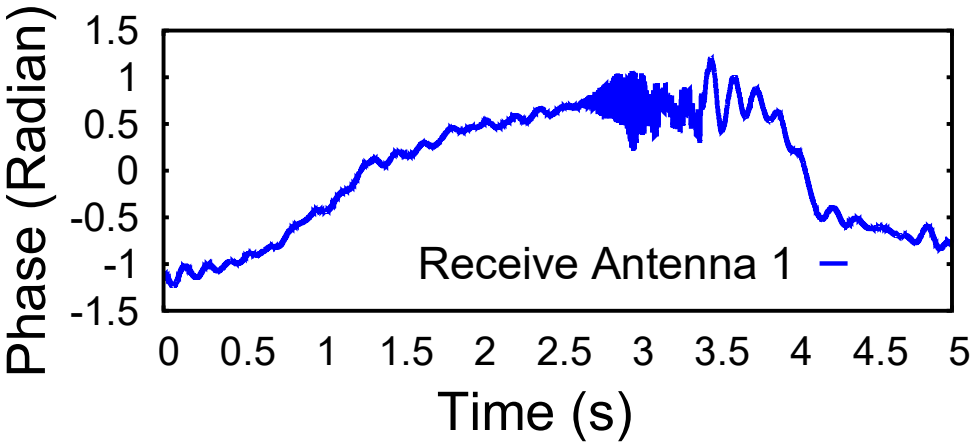


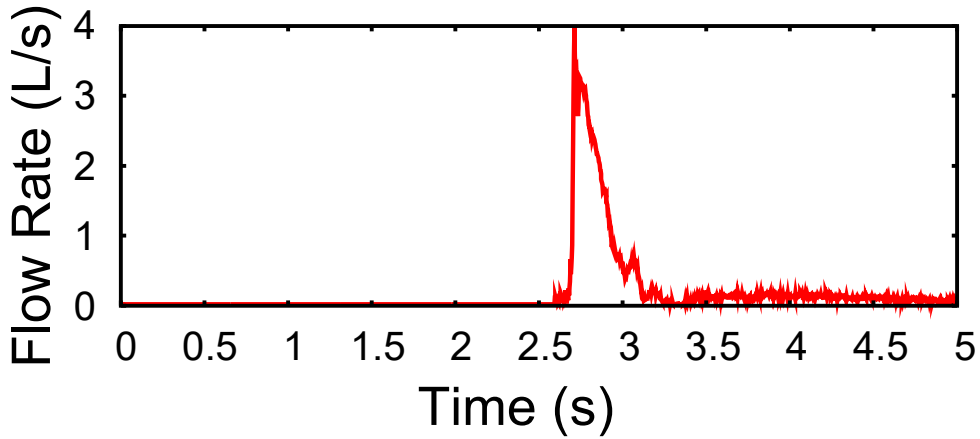
mmFlow Design: Airflow Vibration Estimator

1. A person blows into phone



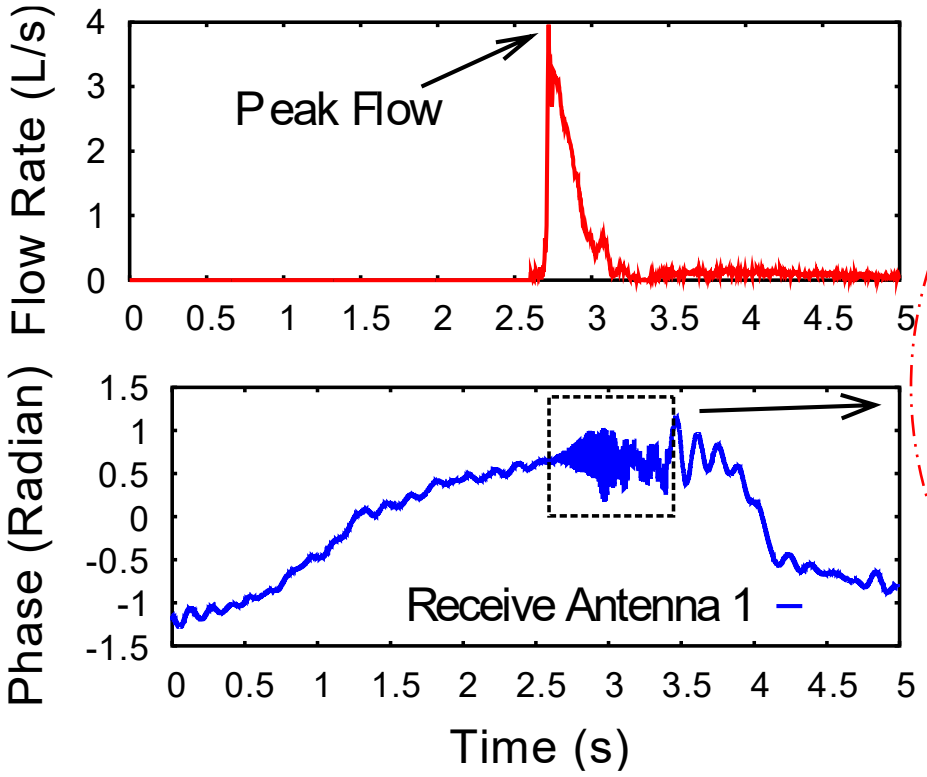
2. Airflow creates tiny vibrations

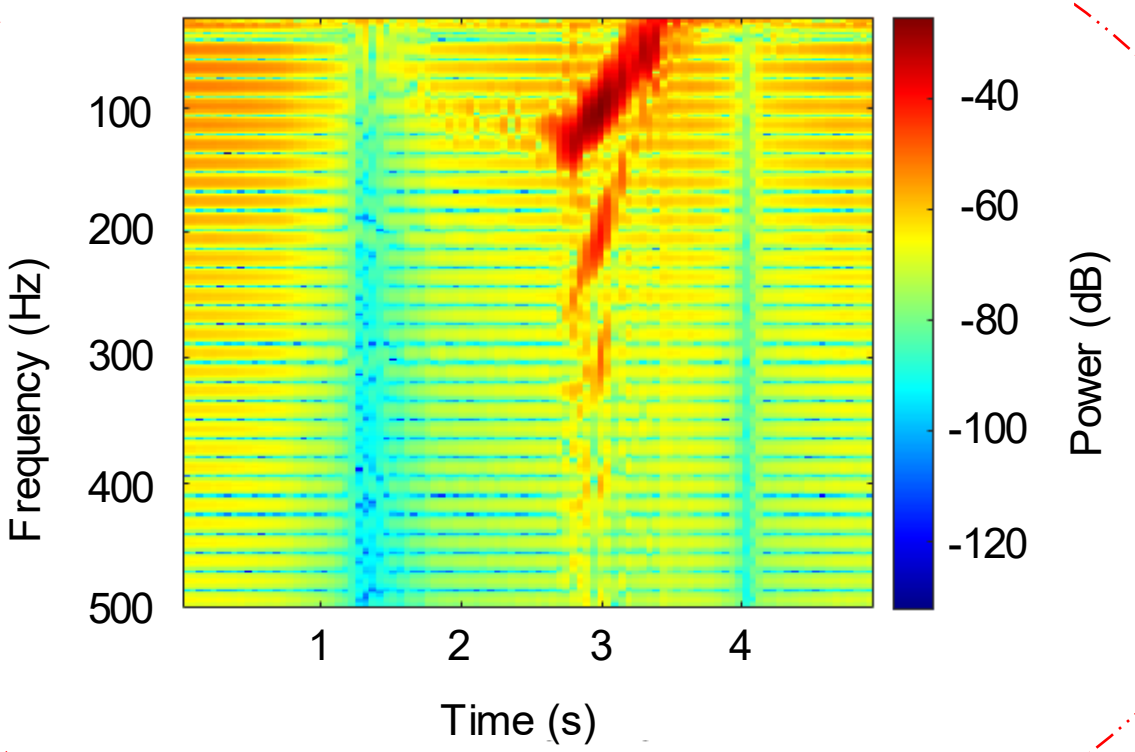




3. Vibrations directly affect the phase of reflected mmwave signal

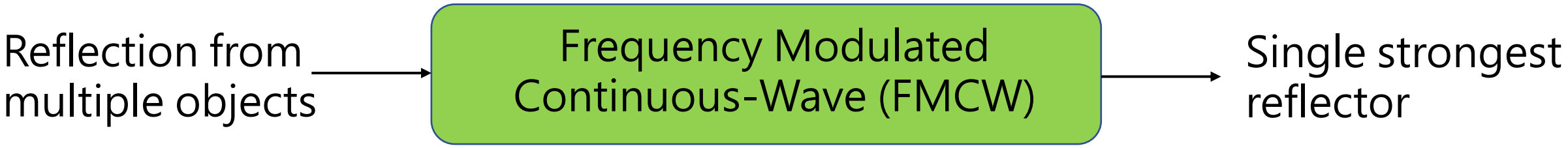
mmFlow Design: Airflow Vibration Estimator





Distinct Vibratory Signal

mmFlow Design: Airflow Vibration Estimator



Hand or body motion

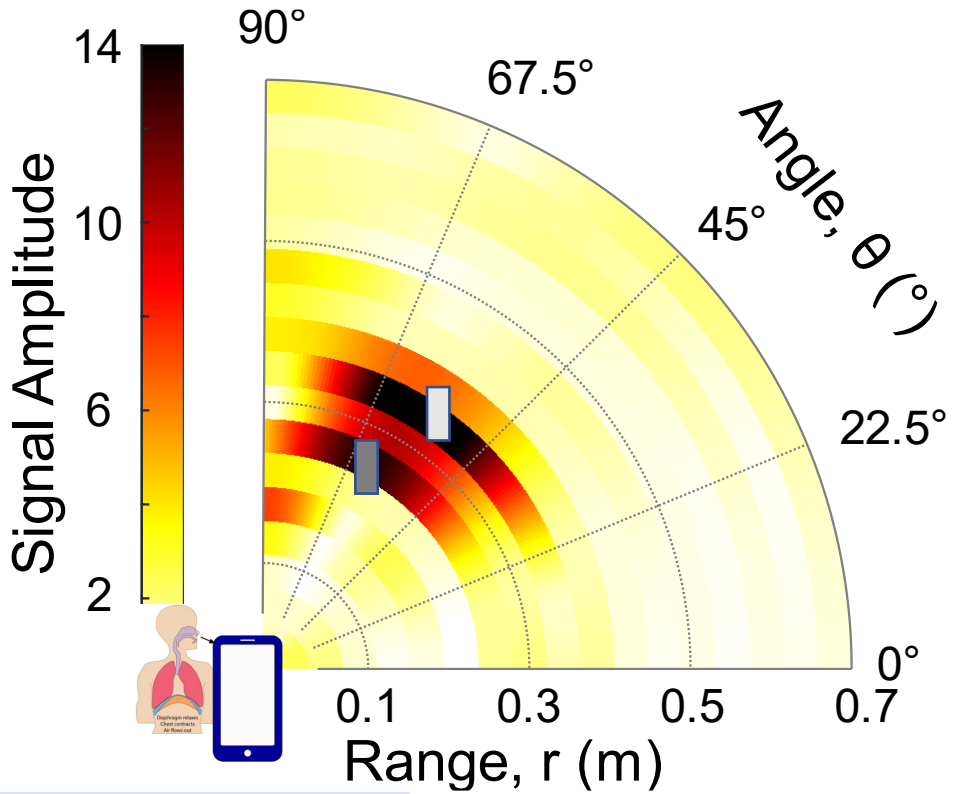
Change in device relative location w.r.t the reflector

Beamforming and Reflector Tracking

Measures reflected signals from multiple antennas

Scans nearby region to find the strongest reflector

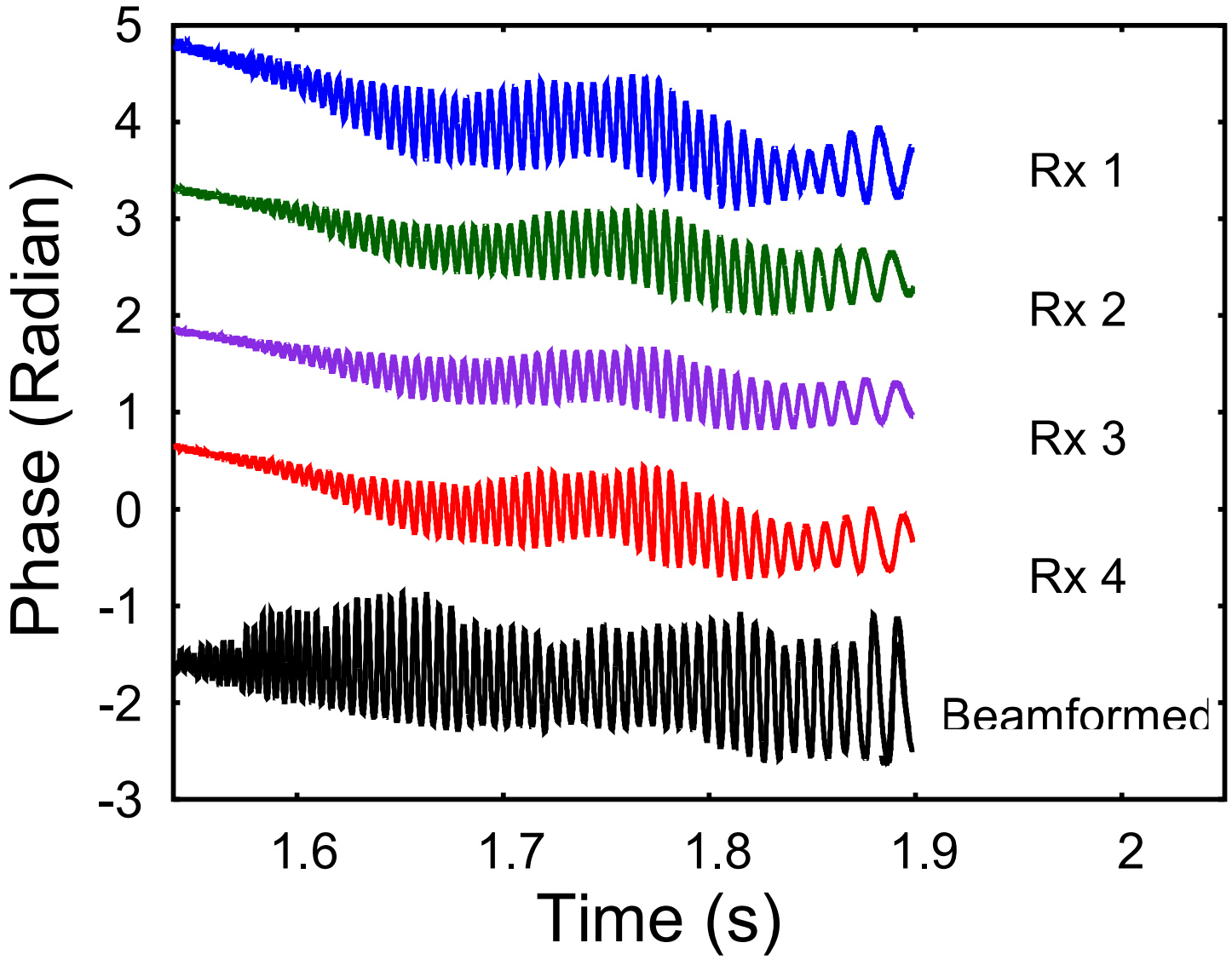
$$\{r^*, \Theta^*\} = argmax\{|BF(r, \Theta)|\}$$



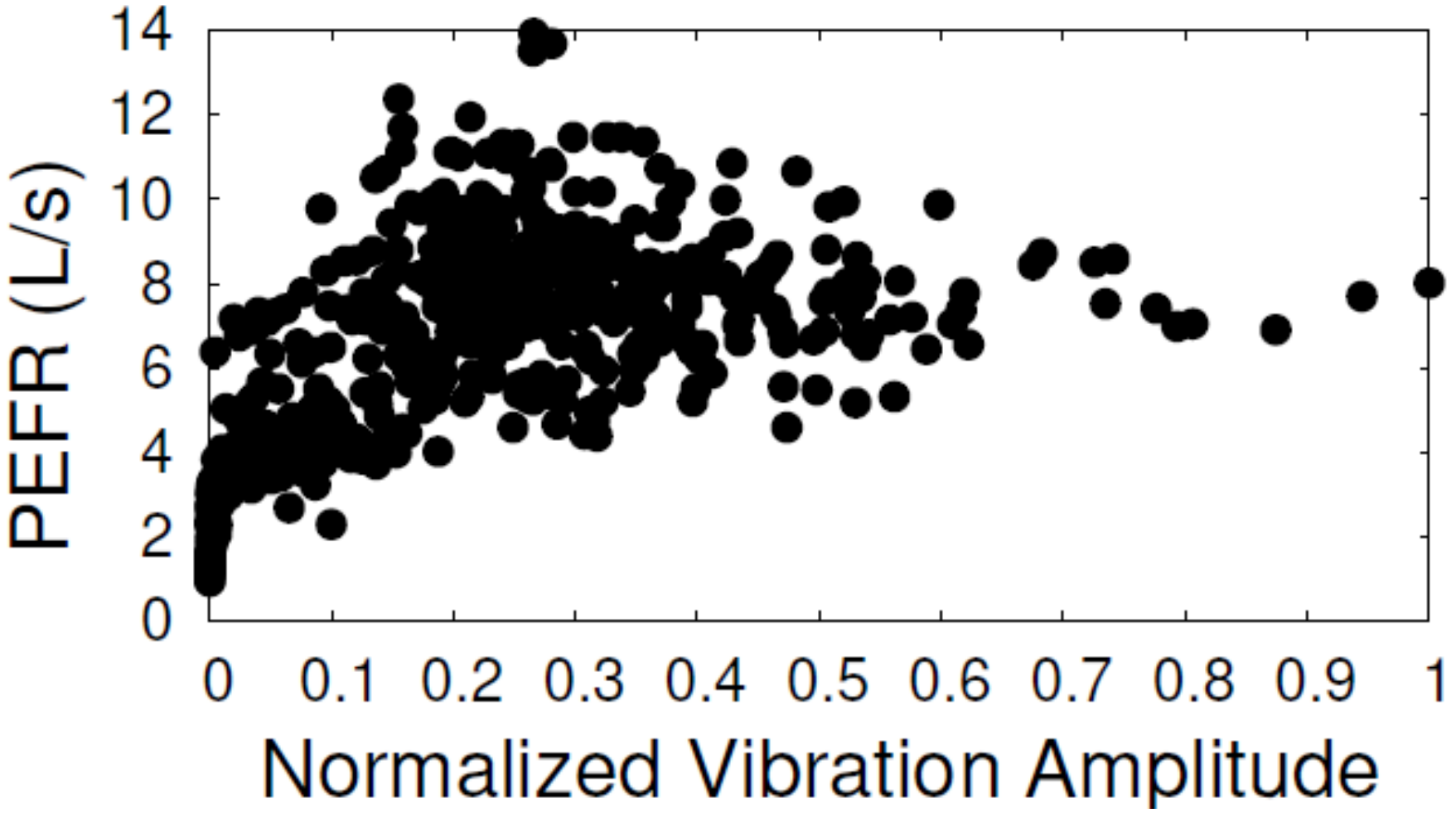
Updates based on shortest Euclidean distance

Traditional beamforming : https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7084678

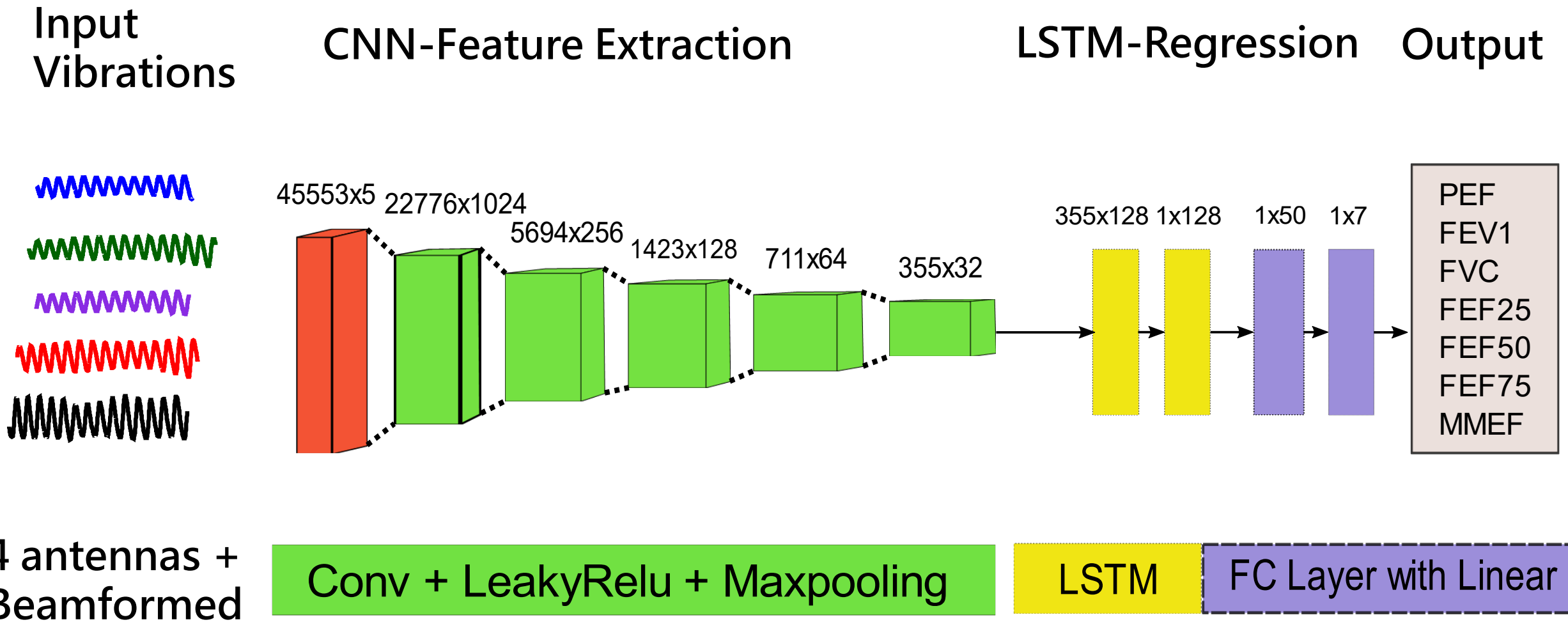
Beamforming and Reflector Tracking



mmFlow Design: Vibration to Spirometry Predictor



mmFlow Design: Vibration to Spirometry Predictor

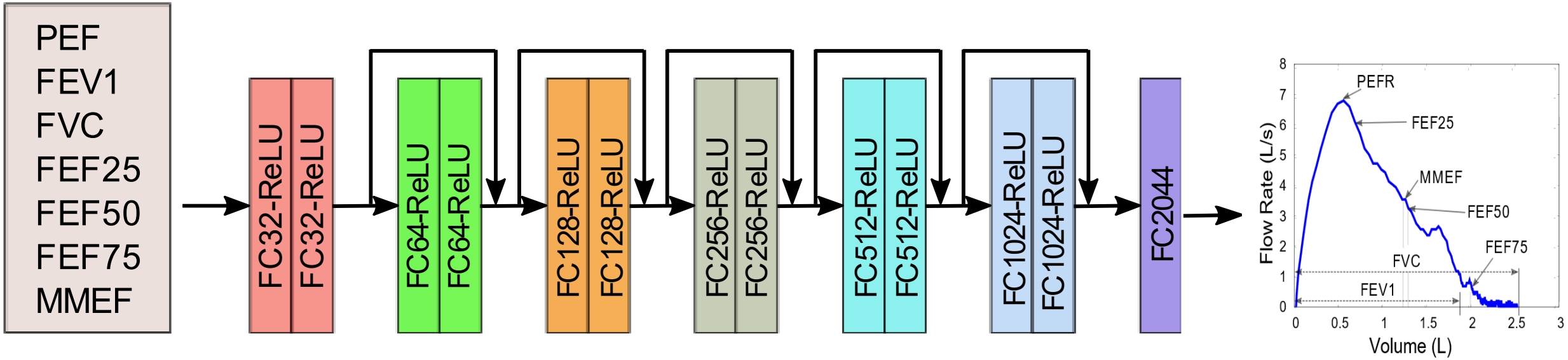


mmFlow Design: Deep Residual Decoder

Input

Stacked Fully Connected Layers

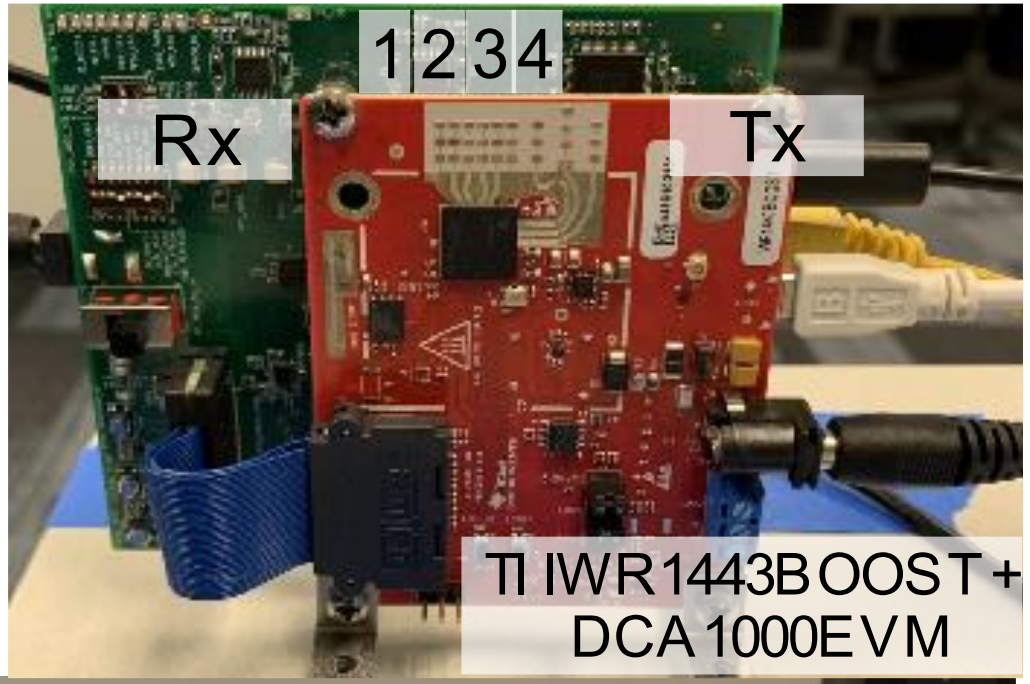
Output

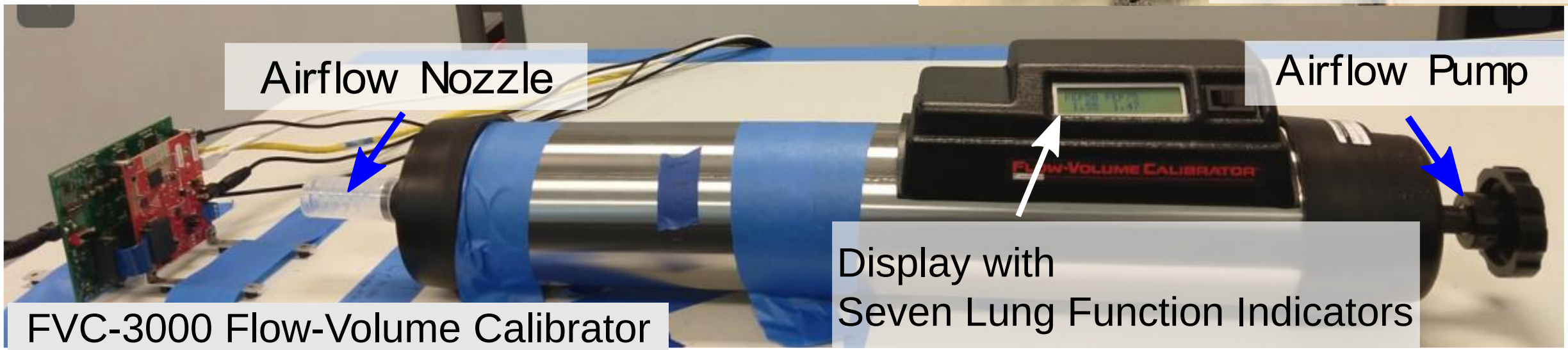


Data_source: CDC: https://wwwn.cdc.gov/Nchs/Nhanes/2007-2008/SPXRAW_E.htm

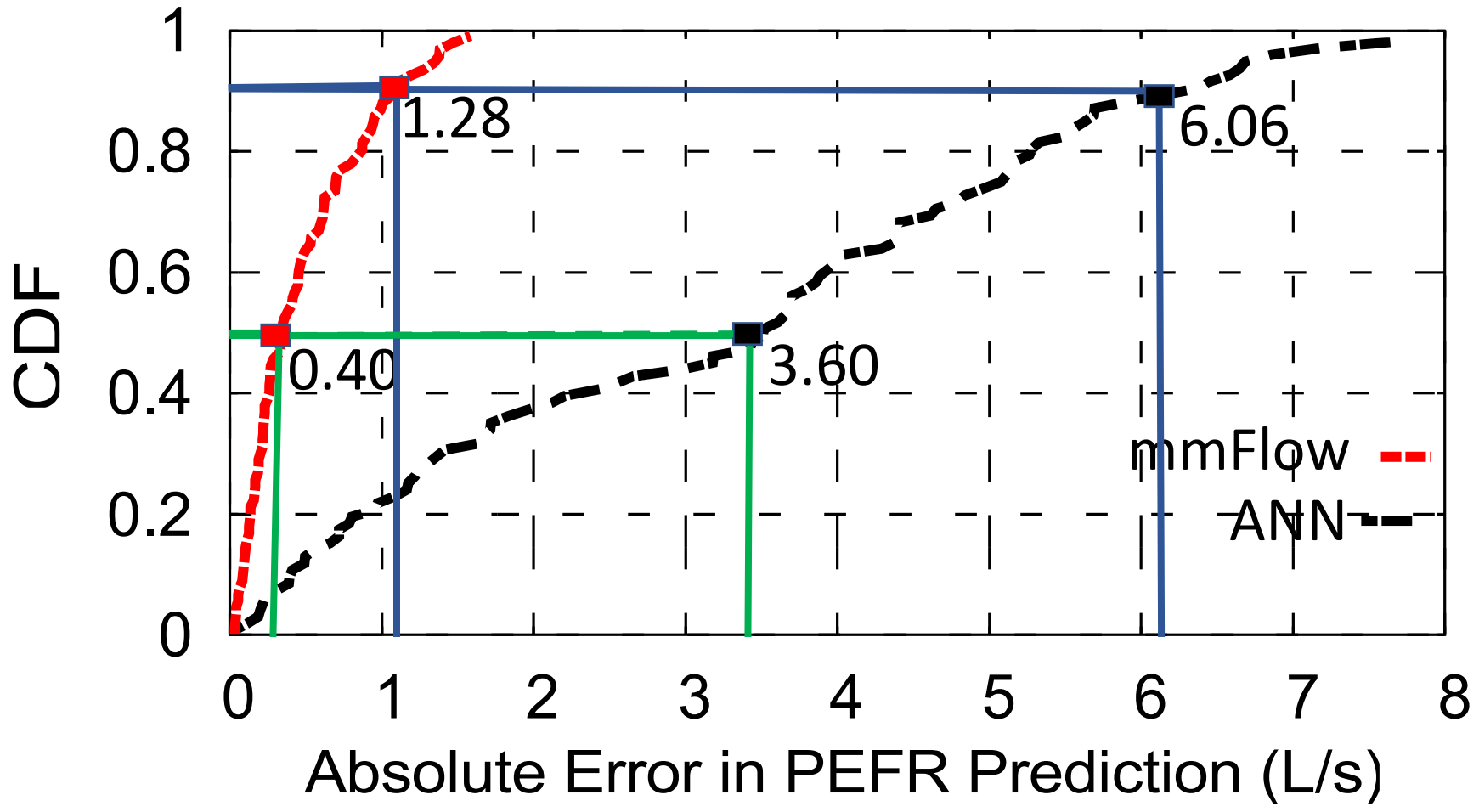
Experimental Platform

- 77-81GHz mmWave device TI IWR 1443BOOST
- 4 receive antennas in mmWave device
- Flow-Volume Calibrator , Jones Medical FVC-3000



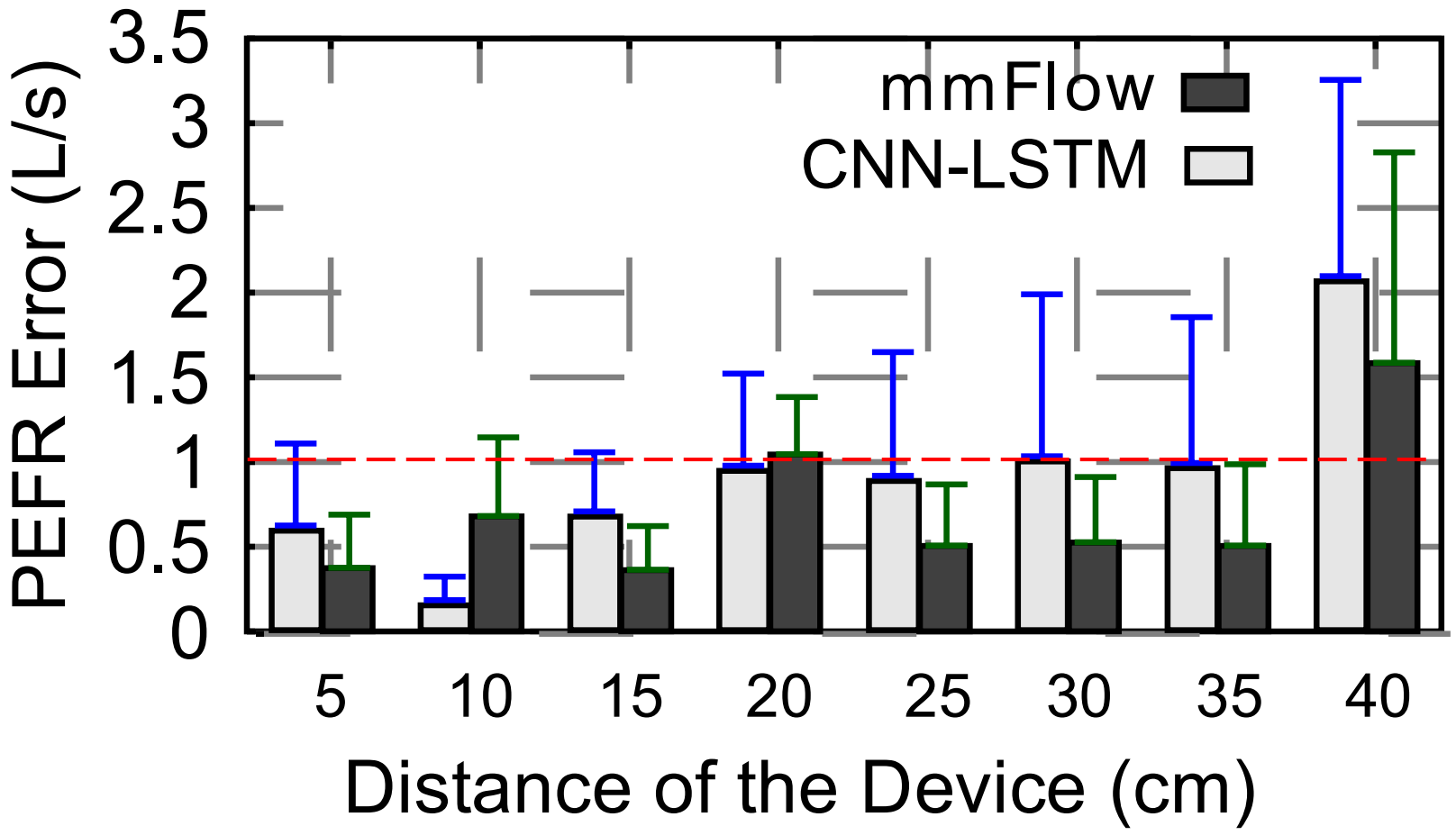


Lung Function Prediction



90th percentile error of mmFlow is 1.28 L/s, which is similar to in-clinic spirometers

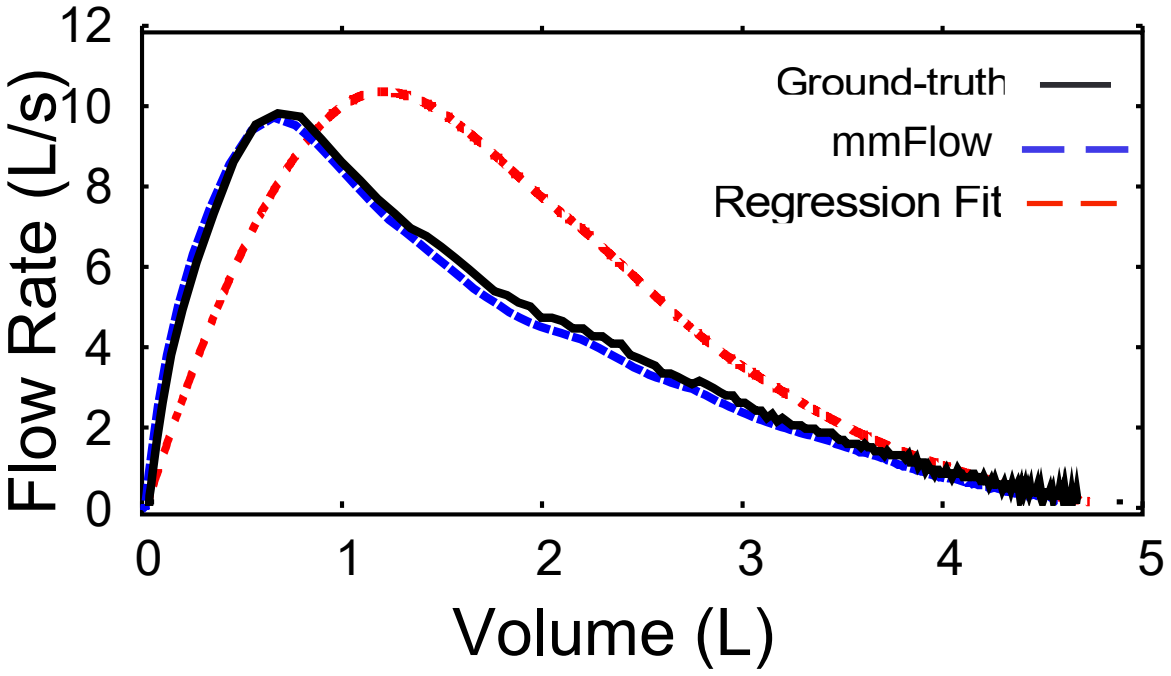
Impact of Device Distance



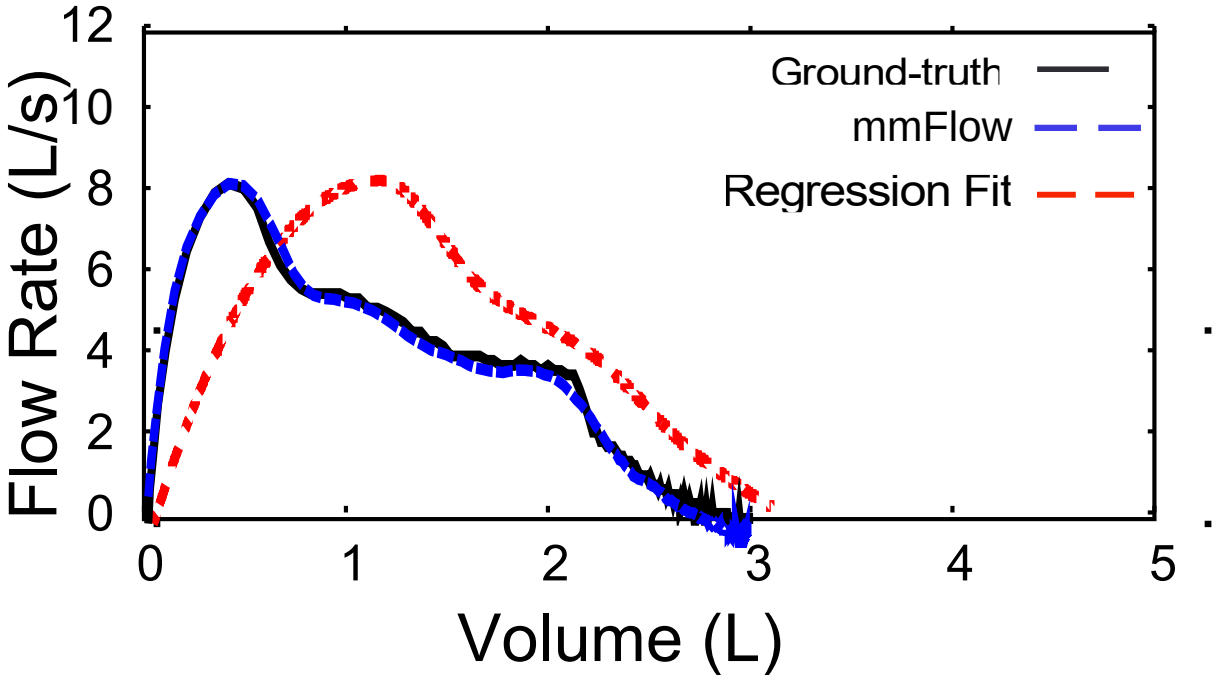
mmFlow works very well for device distance upto 35 cm

Deep Residual Decoder

Healthy

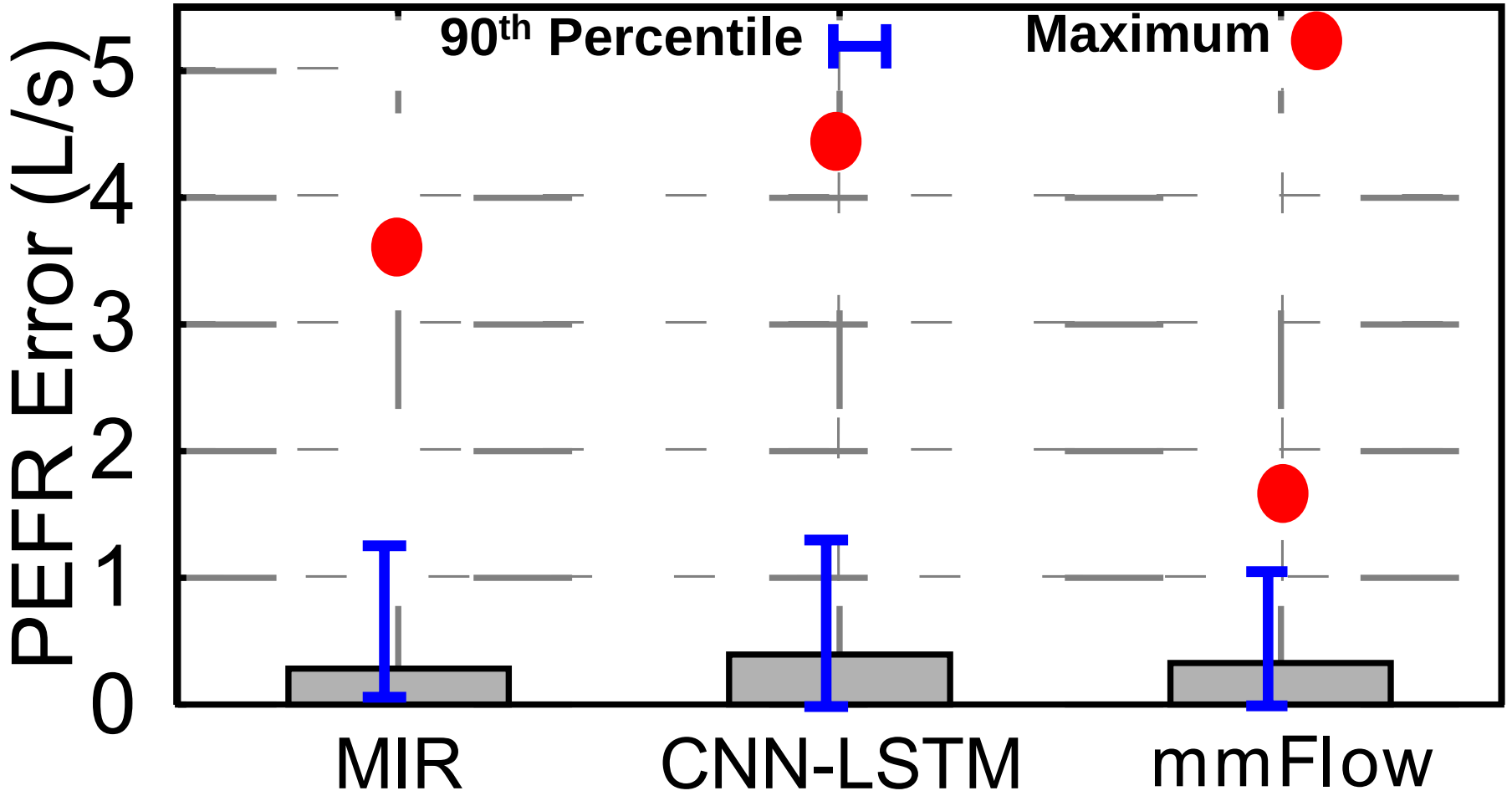


COPD



mmFlow produces accurate graphs for both healthy and diseased patients

Comparison with MIR Portable Spirometer



mmFlow produces results similar to clinically-validated commercial spirometers

mmFlow Summary

System summary

- mmFlow is a first-of-a-kind mmWave based spirometry solution
- mmFlow employs beamforming, reflector tracking, and machine learning to perform spirometry
- mmFlow generalizes well under real conditions
- mmFlow is developed as software-only solution to 5G mobile devices
- In the post-COVID era, mmFlow can transform 5G smartphones into at-home spirometers for non-intrusive lung function monitoring