TagBreathe: Monitor Breathing with Commodity RFID Systems

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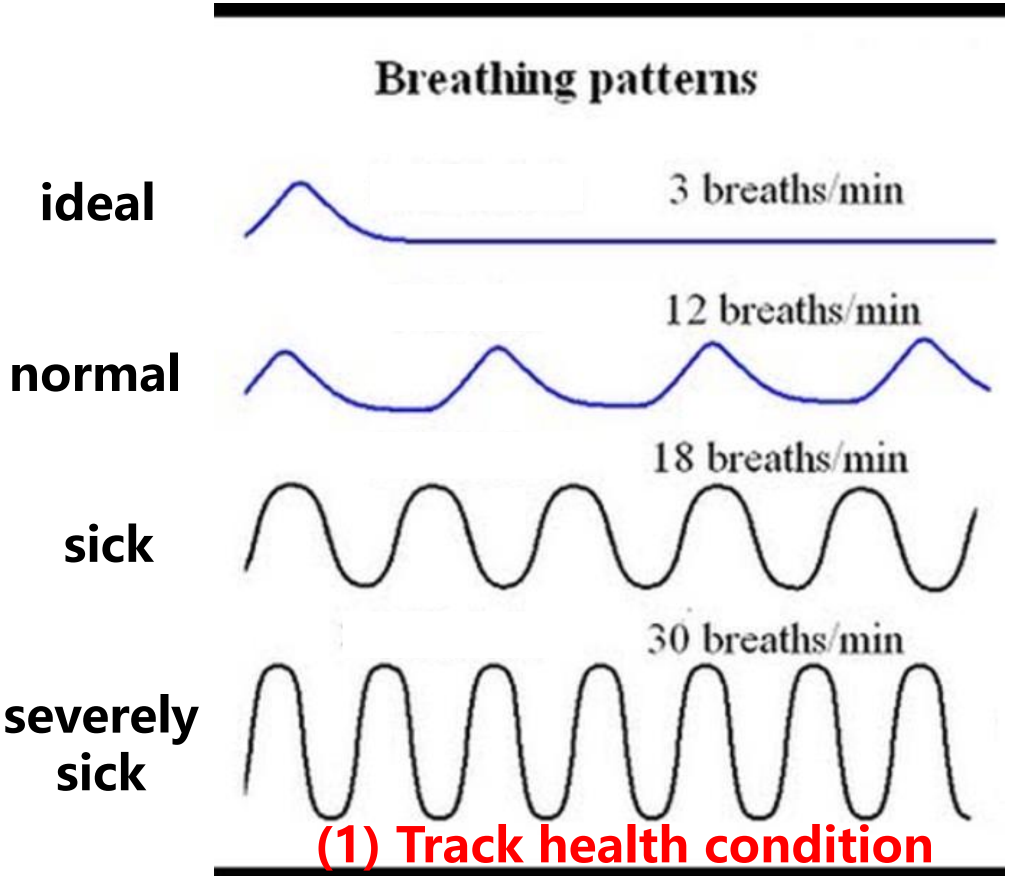
June 7, 2017

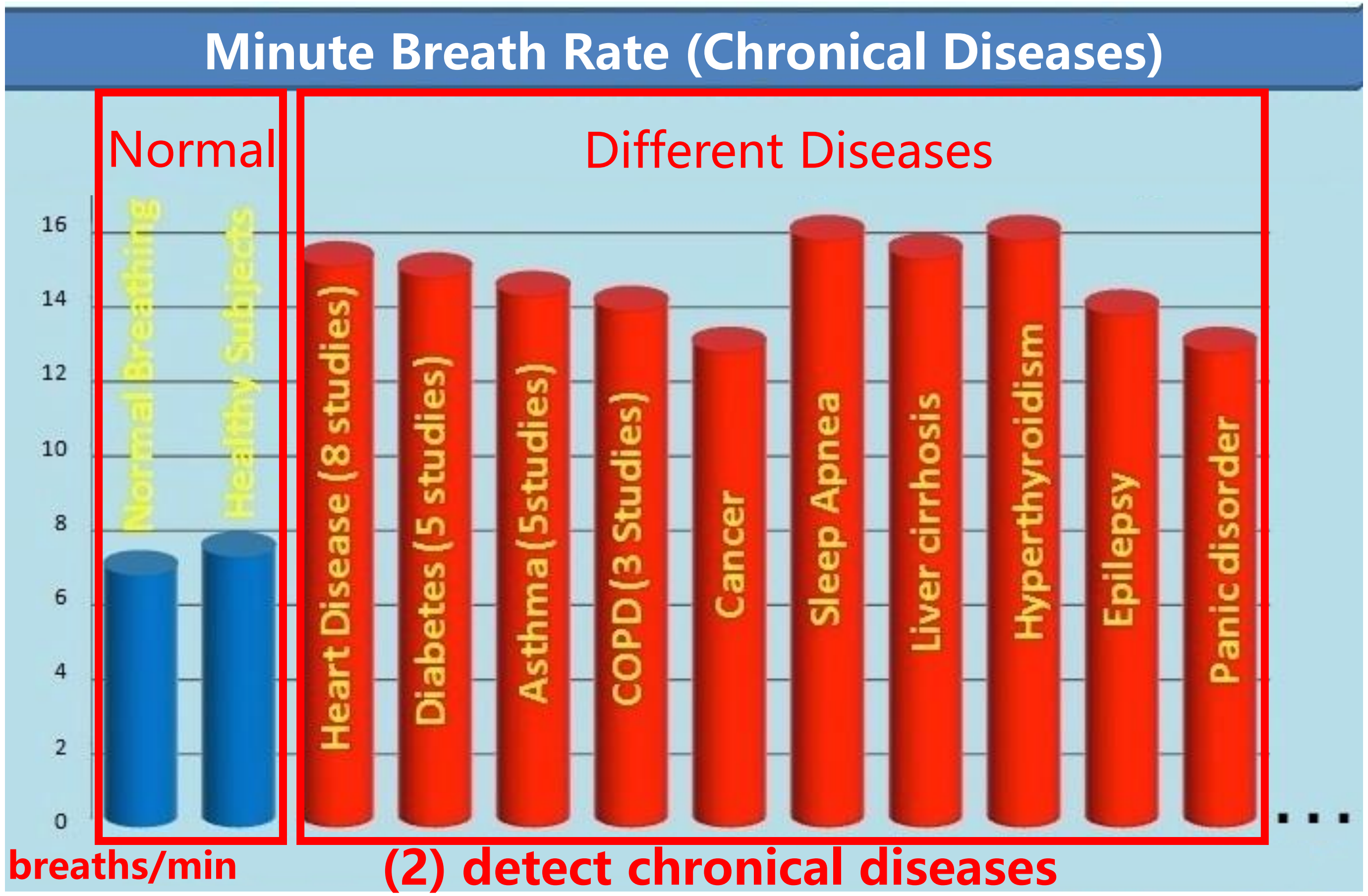
Content

- Importance of Human Respiration Monitoring
- Background and Related Work
- The *TagBreathe* System
- Implementation & Evaluation
- Conclusion

Importance of Human Respiration Monitoring

Medical evidence suggests that sick people are heavy breathers. Respiration rates are different for different diseases.





Data resource: www.NormalBreathing.com Year: 2016

Human Respiration Monitoring in Hospital

Respiration is a key index of human health

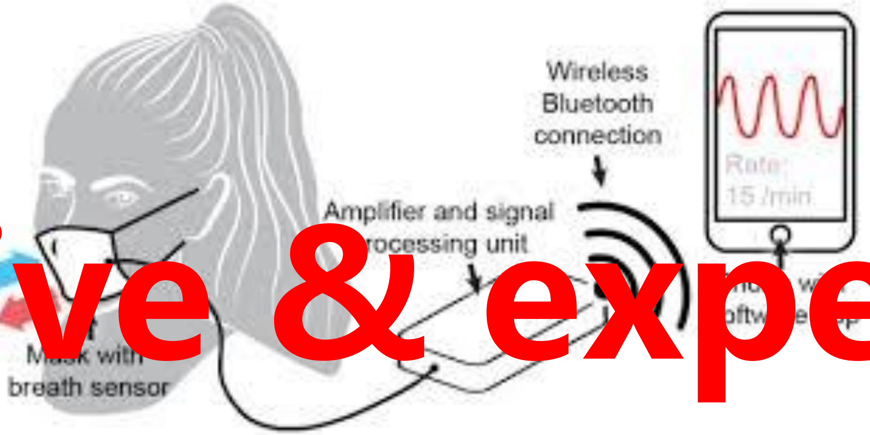

intrusive & inconvenient !

Current Industry Products

- **Industry**

Respiration Monitor Belt

Respiration Monitor Mask



Abdomen Respiration Sensor

intrusive & expensive !

Vital Sign Monitor

Respiration Monitor Probe

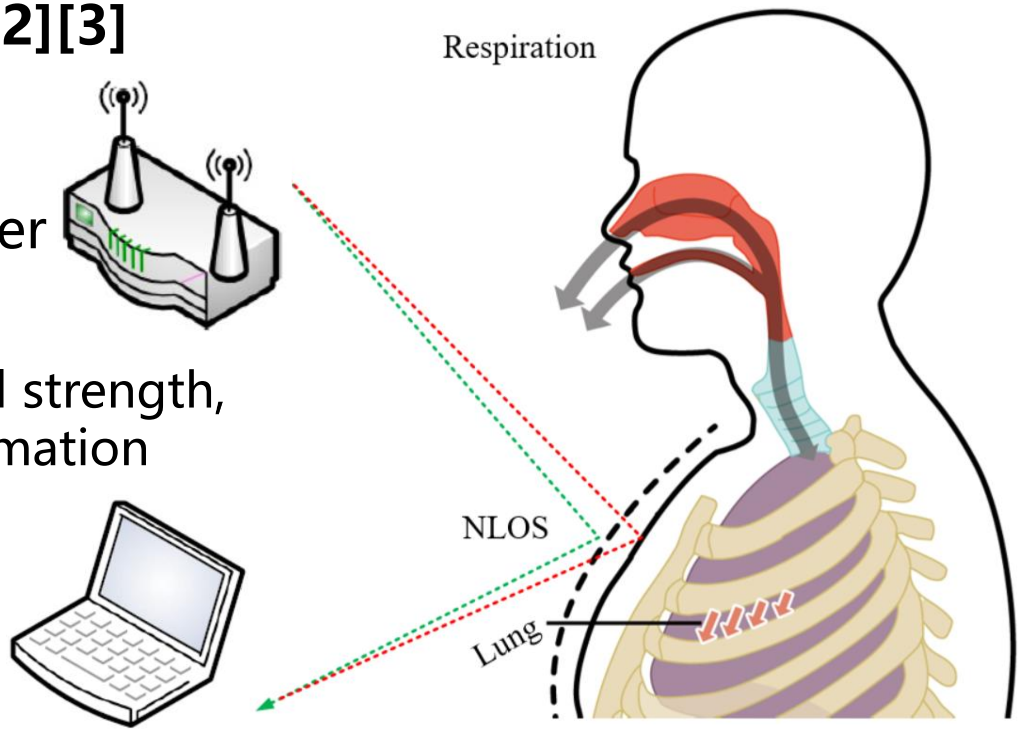
Related Work

- **Research**
  - ➢ **RF signal based respiration monitoring**
    - ➢ **WiFi [1][2][3]**

WiFi router

e.g., received signal strength,
channel state information

Laptop



inhalation & exhalation

tiny chest movement

signal travelling distance change

RSSI, CSI change

1. H. Abdelnasser, *et al*, "UbiBreathe: A Ubiquitous non-Invasive WiFi-based Breathing Estimator", ACM MobiHoc, 2015
2. X.F. Liu, *et al*, "Contactless Respiration Monitoring Via Off-the-Shelf WiFi Devices", IEEE Transaction on Mobile Computing, 2016
3. H. Wang, *et al*, "Human Respiration Detection with Commodity WiFi Devices: Do User Location and Body Orientation Matter?", ACM UbiComp, 2016

Related Work

- **Research**
  - **RF signal based respiration monitoring**
    - **FMCW (Frequency Modulated Carrier Waves) [4]**

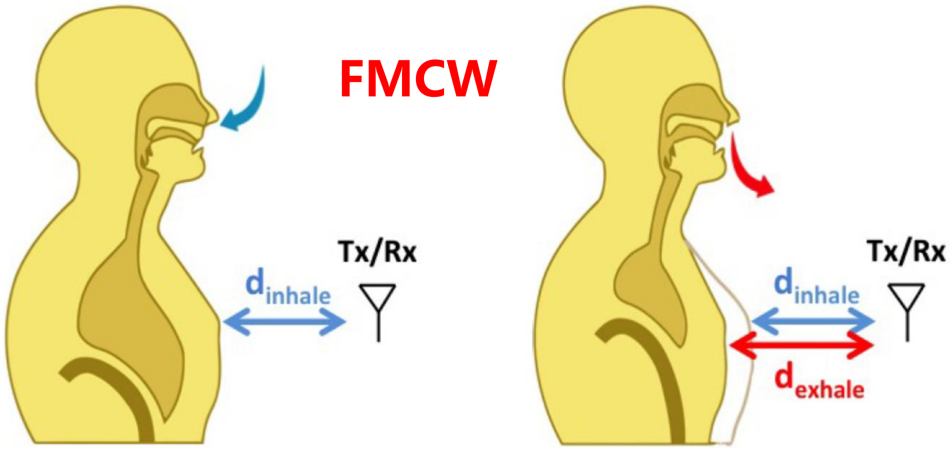
inhalation & exhalation

↓

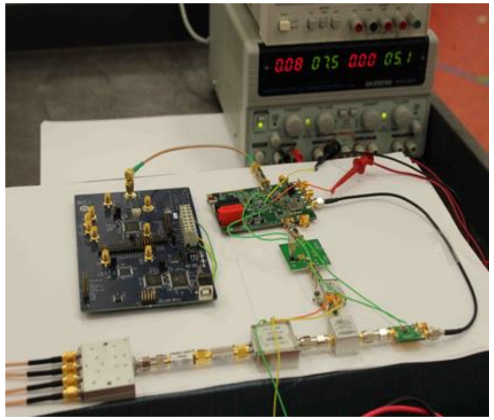
tiny chest movement

↓

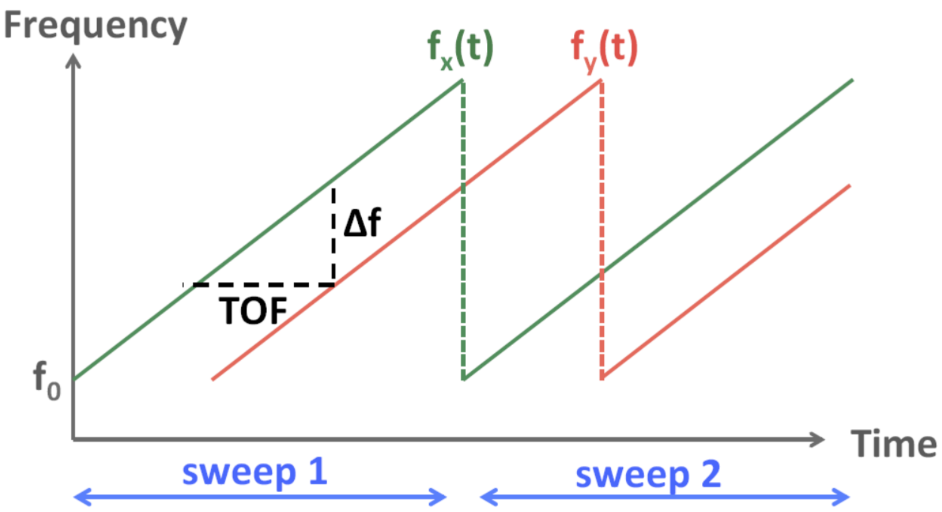
signal travelling distance change



FMCW: linearly increased frequencies



$$TOF = \Delta f / slope$$



4. F. Adib, *et al.*, "Smart Homes that Monitor Breathing and Heart Rate", ACM CHI, 2015

Limitation

- **Limitation for existing RF signal based methods**
  - **Low resolution for WiFi system**
  - **FMCW systems require customized active radio, which are not readily available on the market.**
  - **Both systems may fail in detecting multiple persons**

A low cost, non-intrusive and convenient system that is able to detect breaths of multiple persons is needed !

Advantages of RFID systems

- **RFID based methods**
  - ➢ **Widespread use**
  - ➢ **Provides opportunities for nonintrusive cost-effective healthcare monitoring**
  - ➢ **High resolution of 0.038mm movement detection**
  - ➢ **Work for multiple persons**

$5-10 cents each

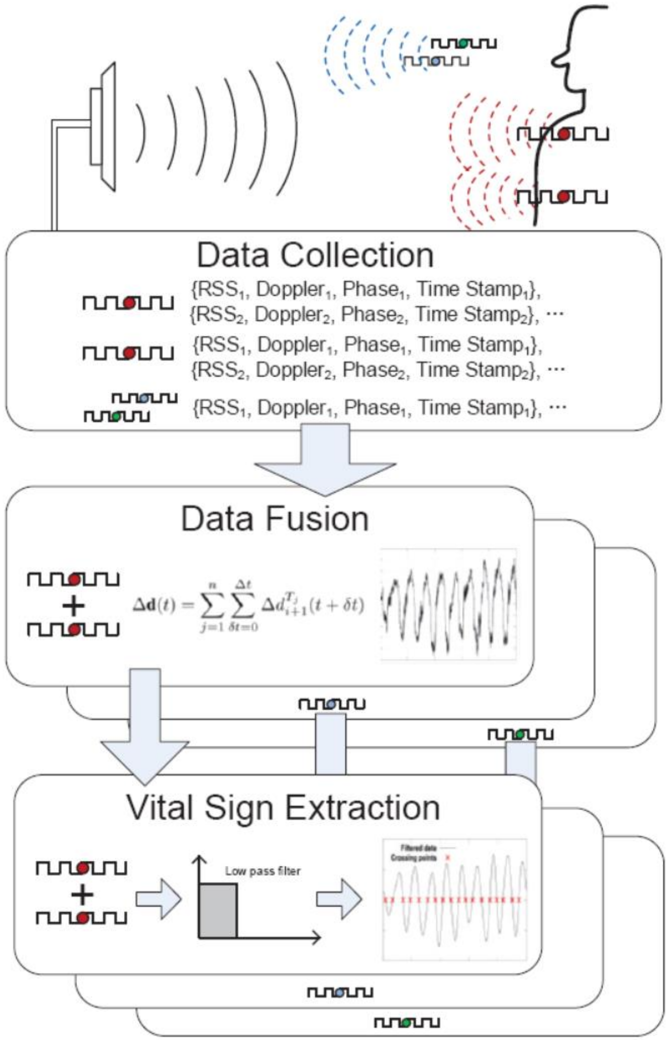
The *TagBreathe* System

- ***TagBreathe* workflow**

Step 1

Step 2

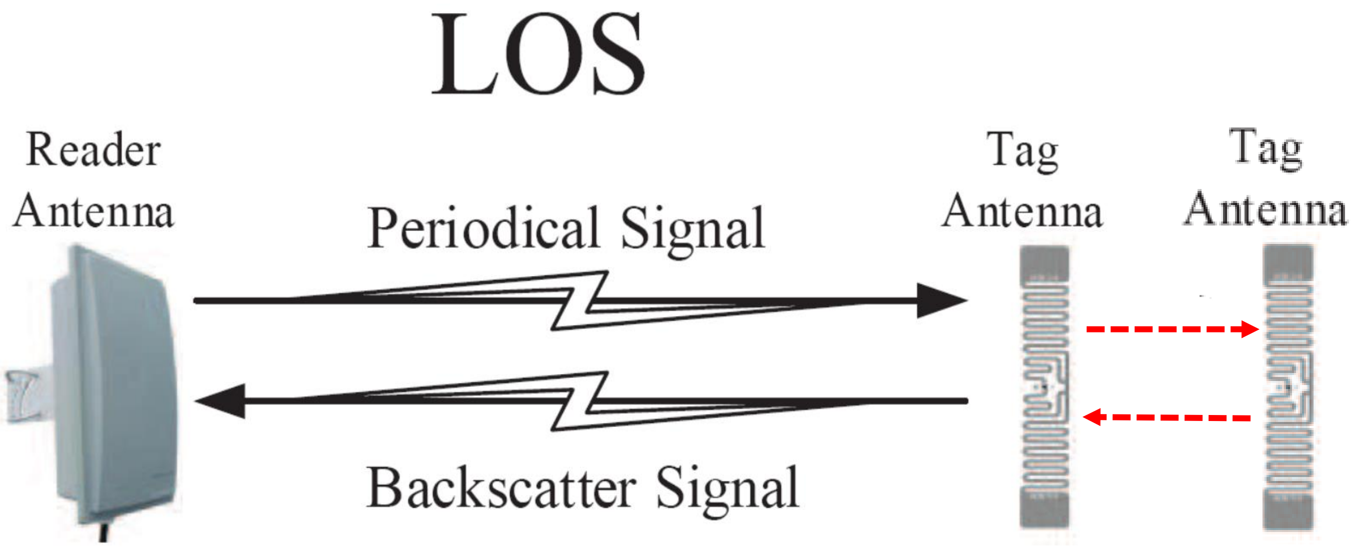
Step 3



Monitor human breath rate

Low Level Data of the Signal

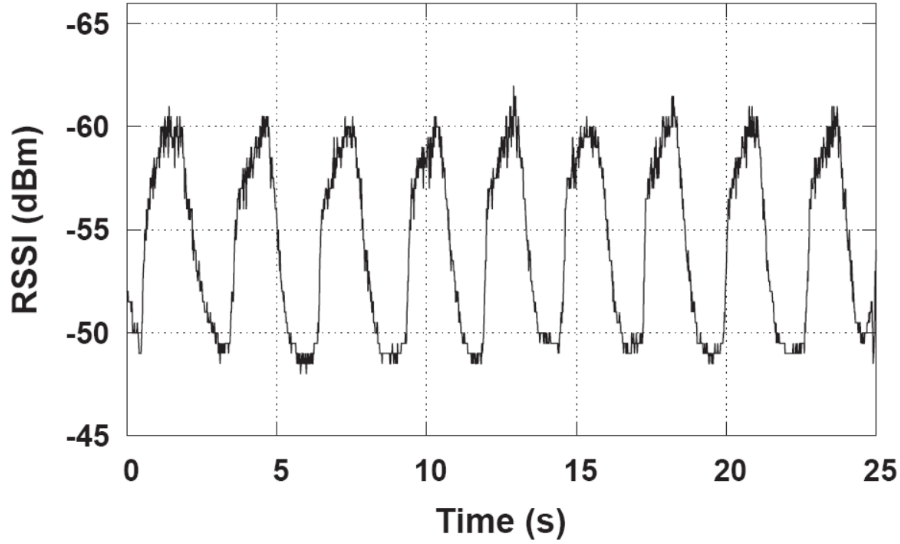
- **Low level data**
  - ❖**RSS (Received Signal Strength)**
  - ❖**DFS (Doppler Frequency Shift)**
  - ❖**SPV (Signal Phase Values)**



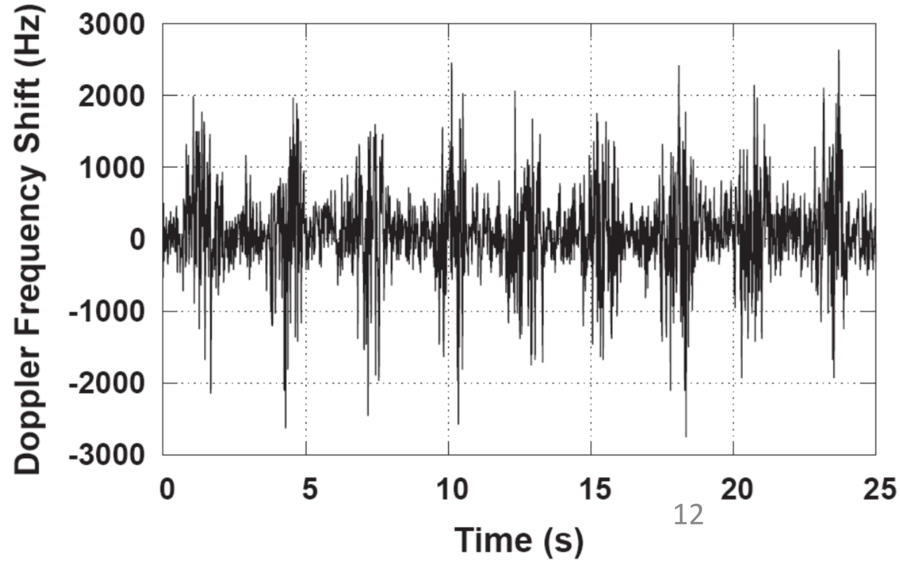
Due to the distance between tag and reader changes periodically, corresponding low level data also changes.

The *TagBreathe* System

- **Limitation of using RSS**
  - ❖ Low resolution
  - ❖ Unavailable in more challenging working scenarios



- **Limitation of using DFS**
  - ❖ *DFS* during the one packet transmission is not reliable and may be subject to noises in practice.
  - ❖ More suitable for high speed movement of tags



The *TagBreathe* System

- **Signal Phase Values**
  - ❖ **High resolution of 0.038mm movement**
  - ❖ **Suitable for both high and low speed movement**

The *TagBreathe* System

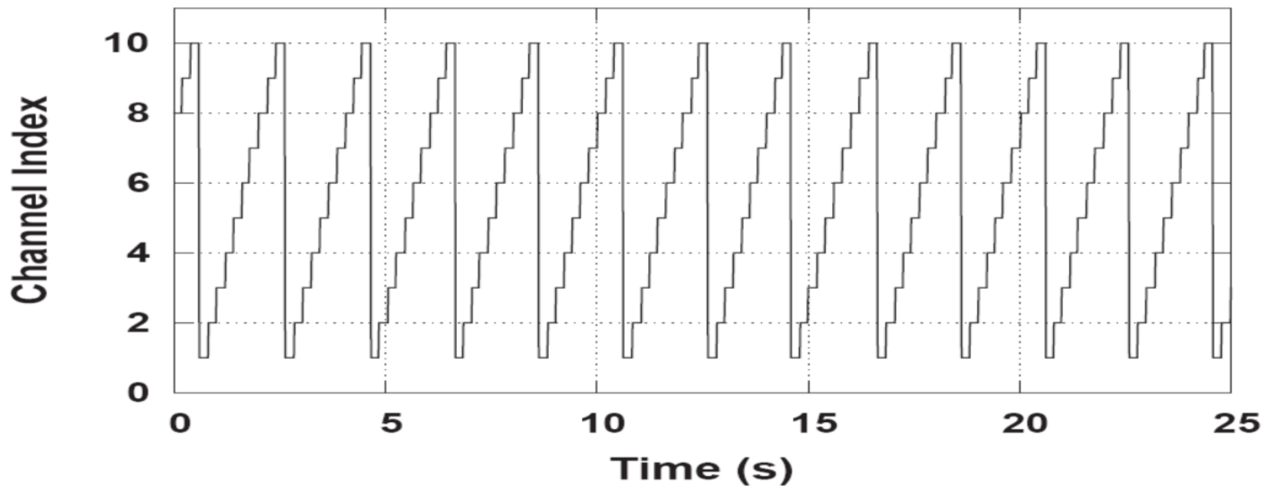
- **Challenge 1: Channel Frequency Hopping in standard EPC protocol**

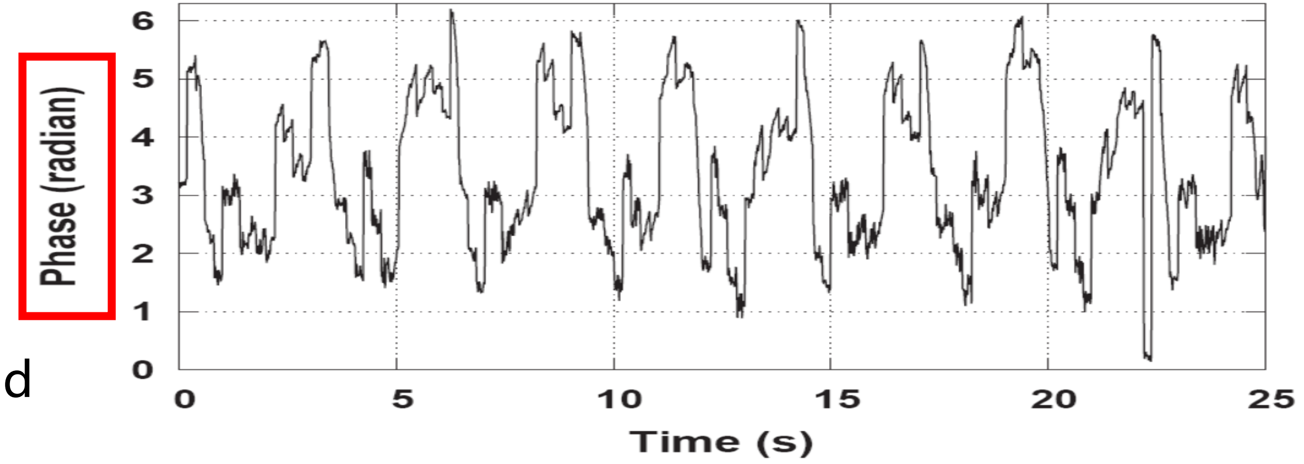
❖ 0.2 seconds for 1 channel

❖ λ and the phase offset change

❖ Discontinuity of phase values for every 0.2s

$$\theta = \left(\frac{2\pi}{\lambda} \times 2d + \theta'\right) \bmod 2\pi$$





phase offset is caused by the circuits of reader and tag, which is independent of the distance

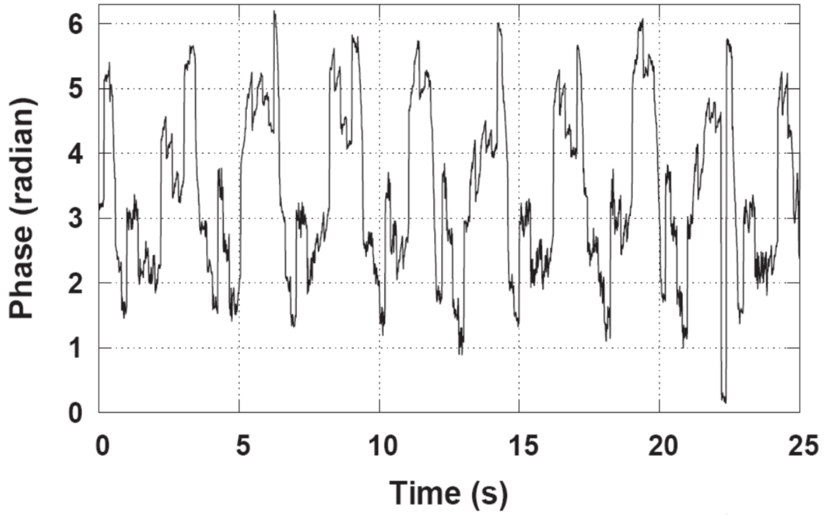
The *TagBreathe* System

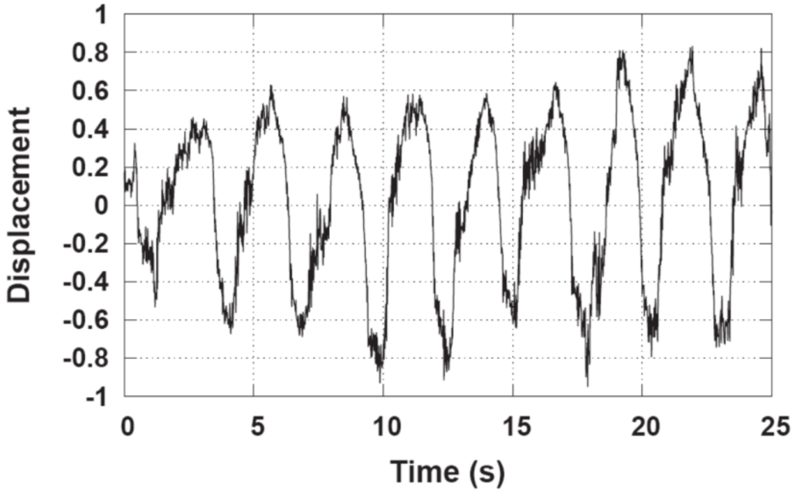
- **Challenge 1: Channel Frequency Hopping in standard EPC protocal**

(1)Group the phase values according to channel indexes.

(2)Then, calculate the displacement during two consecutive phase readings in the same channel to eliminate phase offsets.

$$\Delta d_{i+1} = d_{i+1} - d_i = \frac{\lambda}{4\pi}(\theta_{i+1} - \theta_i) \rightarrow D_j = \sum_{i=1}^{N} \Delta d_{i+j}$$





The displacement values are not influenced by the frequency hopping and track the periodic body movement mainly due to breathing !

The *TagBreathe* System

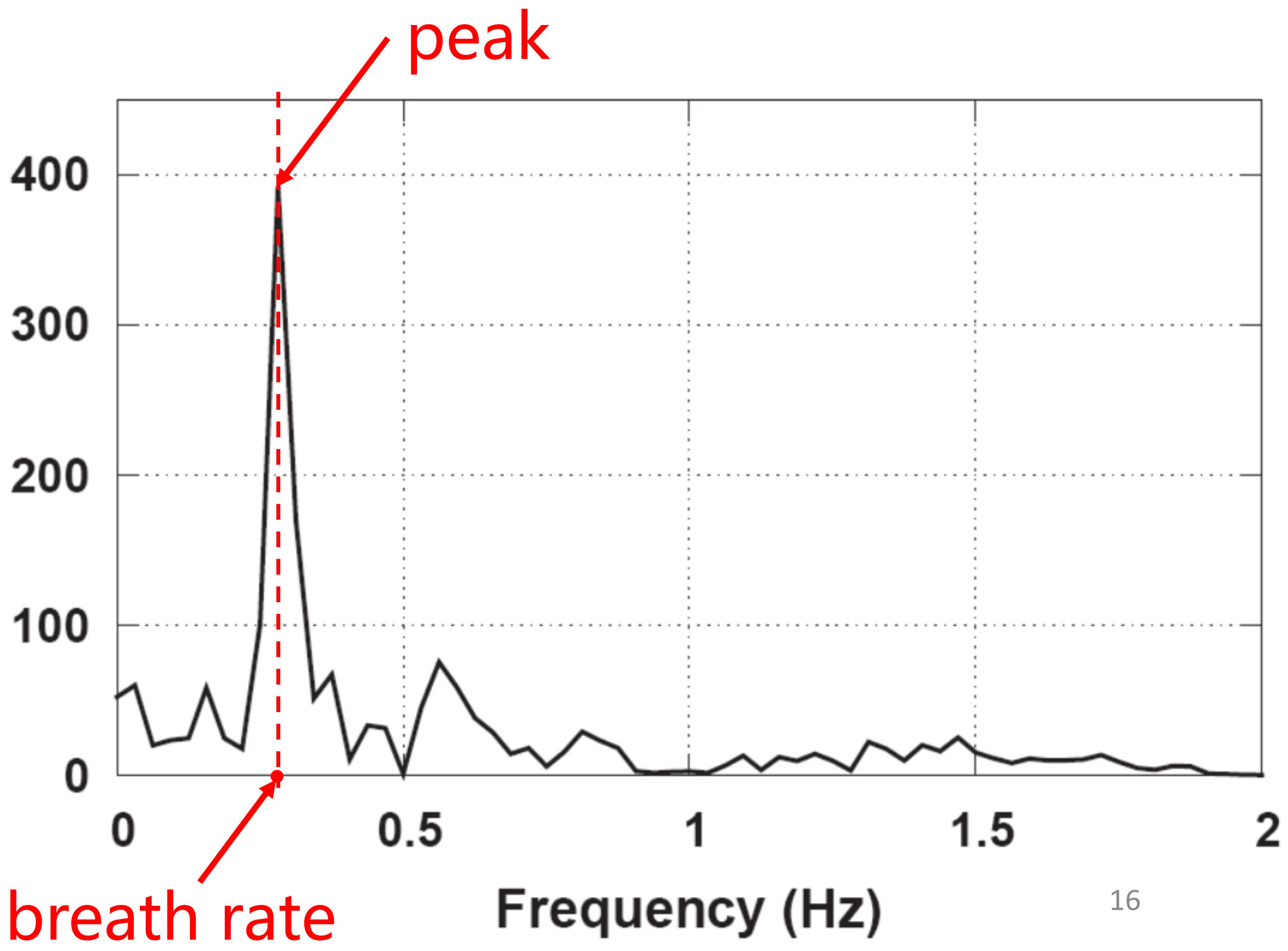
- **Challenge 2: Extract the breath pattern from the waveform**

FFT (Fast Fourier Transform)

The peak of the FFT output corresponds to the breathing rate.

The Fourier transform for a window size of *w* seconds is that it has a resolution of 1/*w*.

In our initial experiment, *w*=25s, the frequency resolution is 0.04 Hz which corresponds to 2.4 breaths per minute.



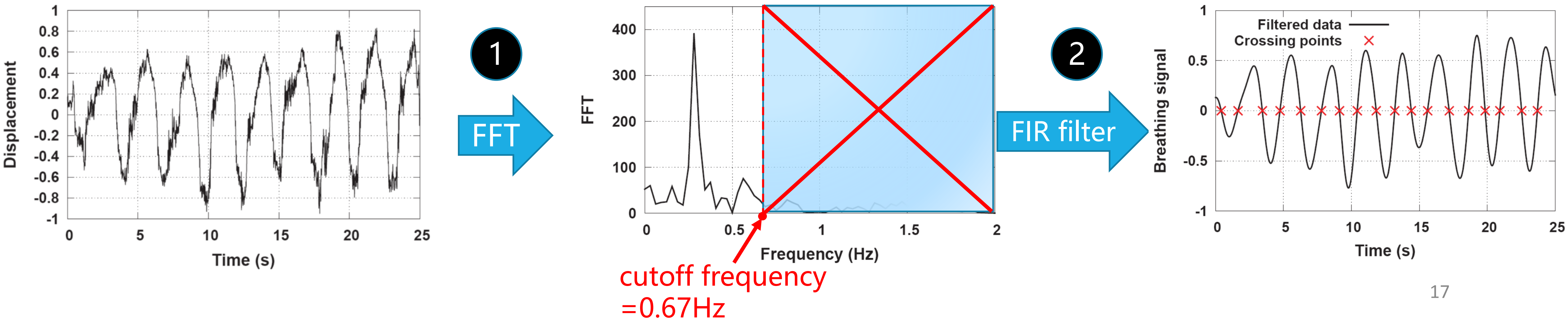
The *TagBreathe* System

- **Challenge 2: Extract the breath pattern from the waveform**

Apply an FFT-based low pass filter to filter out high frequency noises and then extract the breathing signals.

- Average 12 - 20 breaths per minute for a healthy person.
- Lower than 40 breaths per minute.

→ **the cutoff frequency of the low pass filter = 0.67 Hz.**

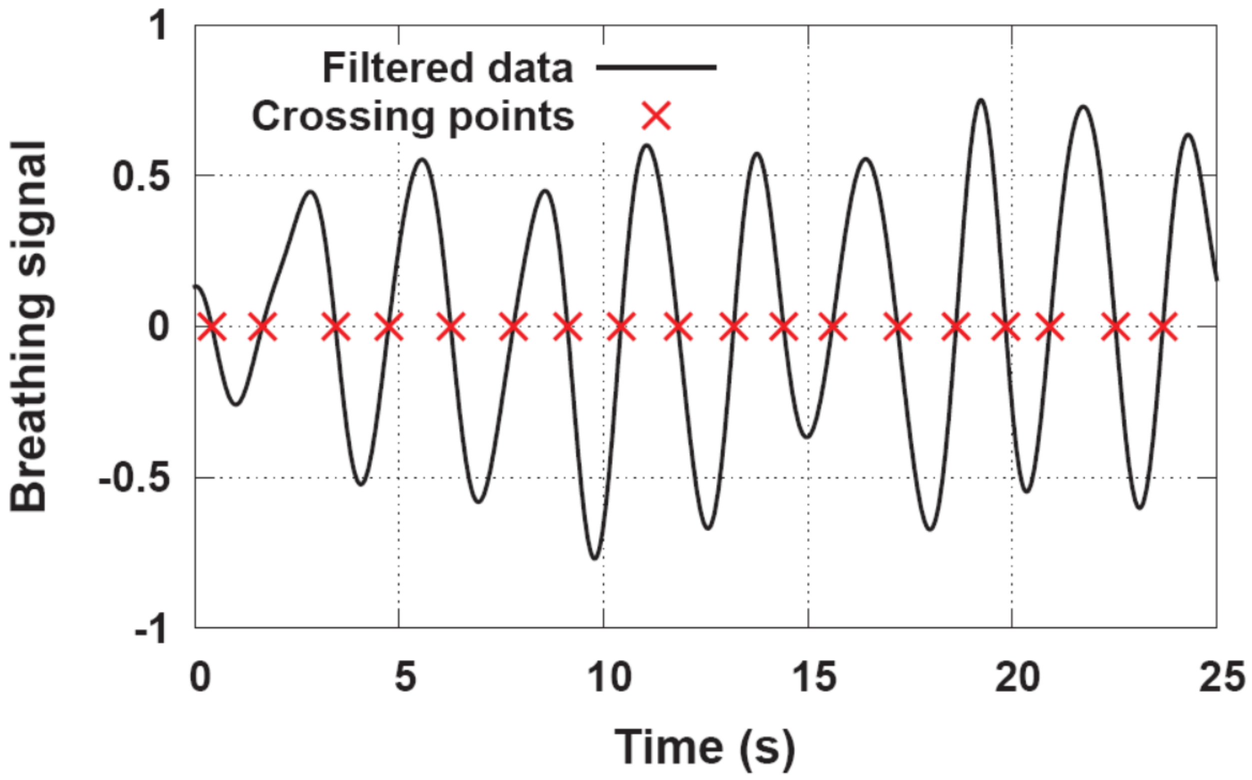


The *TagBreathe* System

- **Challenge 2: Extract the breath pattern from the signal phase values**

Record the time stamps of the zero crossing events and calculate the instant breathing rate as:

1. Count the number of 0-crossing points M during Δt
2. Breath rate = (M-1)/2Δt



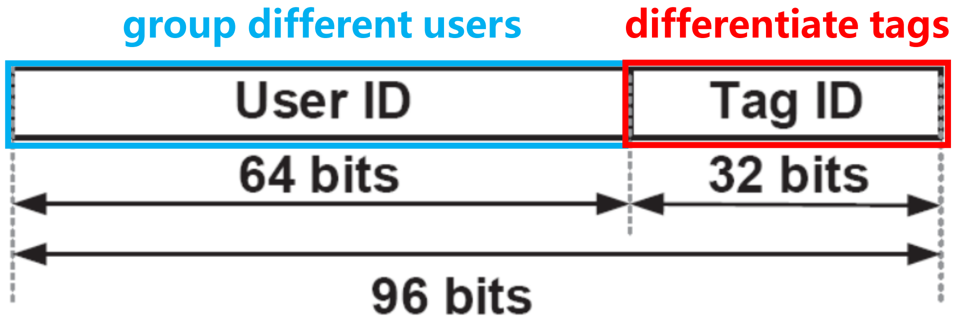
The *TagBreathe* System

- **Challenge 3: Weak signals and NLOS**

With **Sensor Fusion of Multiple Tags**, *TagBreathe* can effectively improve the performance by constructively add raw data, which substantially enhances signal extraction in case that **signals are weak or are blocked in LOS path.**

❖ *TagBreathe* overwrites 96-bit tag ID with 64-bit user ID and 32-bit short tag ID.

❖ We fuse the raw data before extracting breath signals. That is because it can effectively improve signal strength.



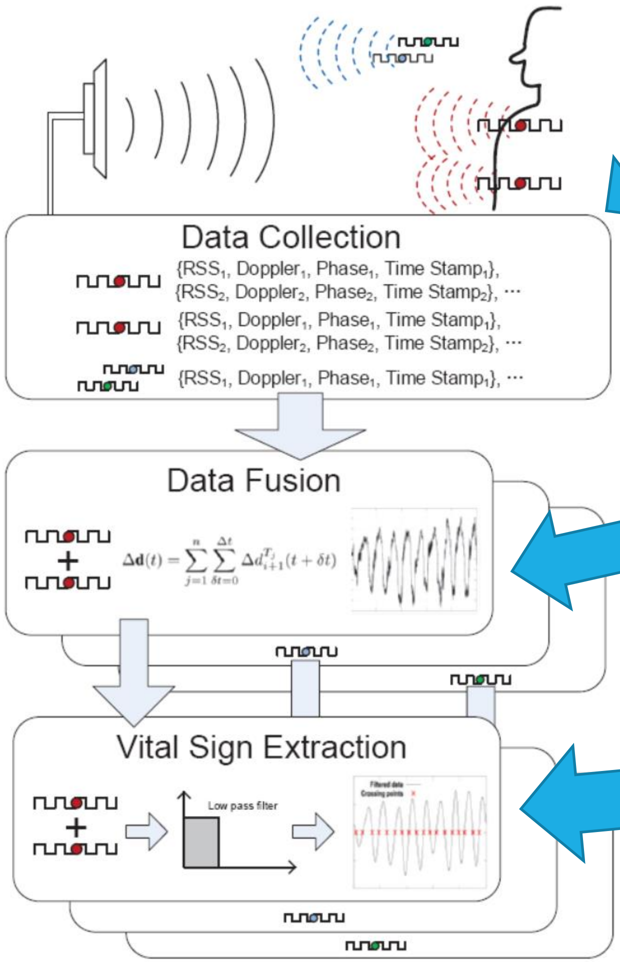
The displacement value for tag T_j collected during the time period $[t, t+\Delta t]$ can be described as:

$T_j: Tag\ j, j \in [1, n]; \delta t \in [t, t+\Delta t]$

$$\Delta \mathbf{d}(t) = \sum_{j=1}^{n} \sum_{\delta t=0}^{\Delta t} \Delta d_{i+1}^{T_j}(t+\delta t) \Longrightarrow \Delta \mathbf{D}(t) = \sum_{i=0}^{N} \Delta \mathbf{d}(t + i\Delta t)$$

The *TagBreathe* System

- ***TagBreathe* workflow**



TagBreathe interrogates multiple RFID tags attached to users and translate the phase value into distance.

$$\Delta d_{i+1} = d_{i+1} - d_i = \frac{\lambda}{4\pi}(\theta_{i+1} - \theta_i)$$

TagBreathe groups the readings and carries out raw data fusion by synthesizing multiple data streams

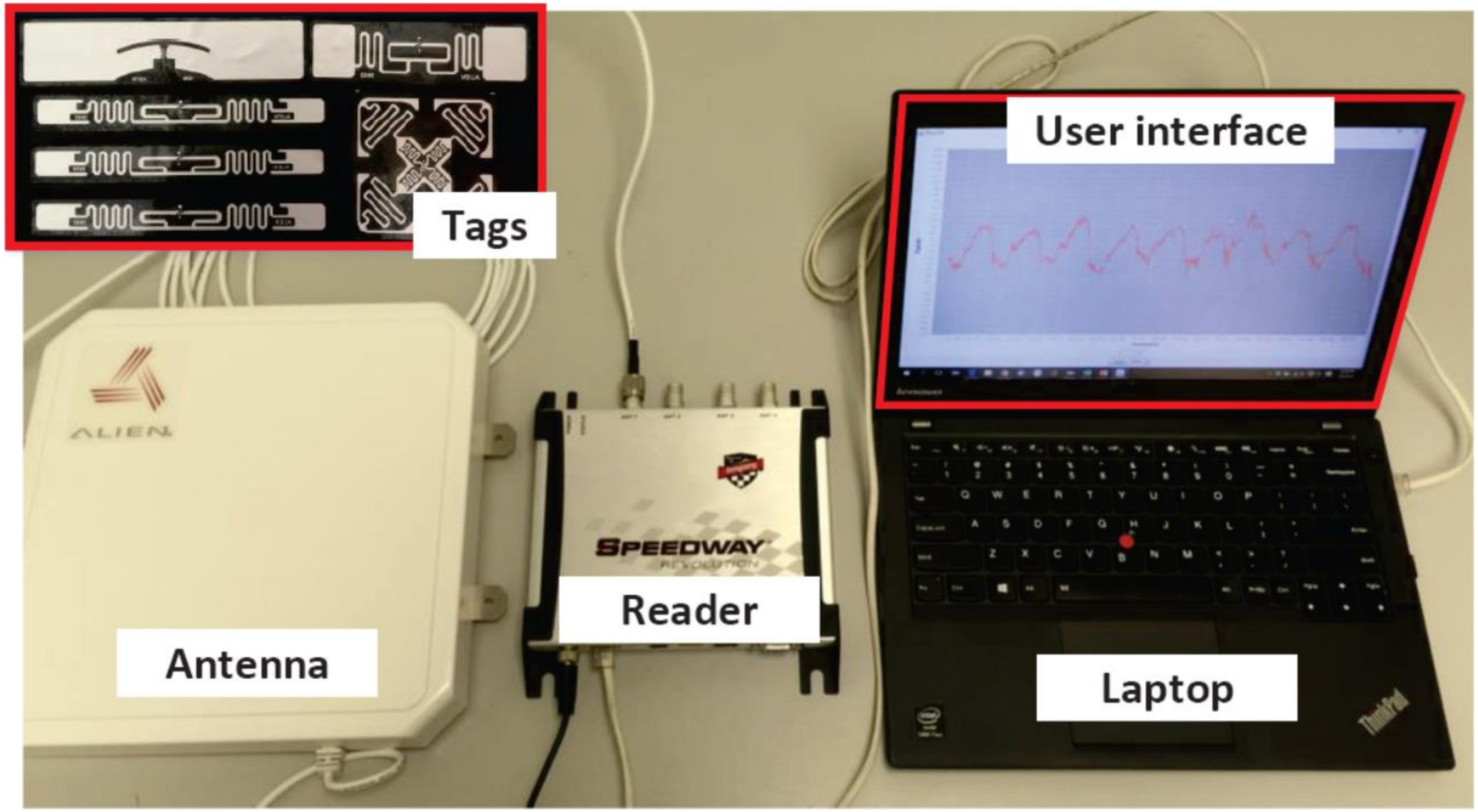
$$\Delta \mathbf{d}(t) = \sum_{j=1}^{n} \sum_{\delta t=0}^{\Delta t} \Delta d_{i+1}^{T_j}(t + \delta t)$$

TagBreathe analyzes the synthesized data stream and extracts breathing signals for each user

$$\overline{f_{BR}}(t_i) = \frac{M-1}{2(t_i - t_{i-M})}$$

Implementation

- ***TagBreathe* prototype system**



We perform a real-time and online implementation of TagBreathe prototype by using COTS RFID.

Evaluation

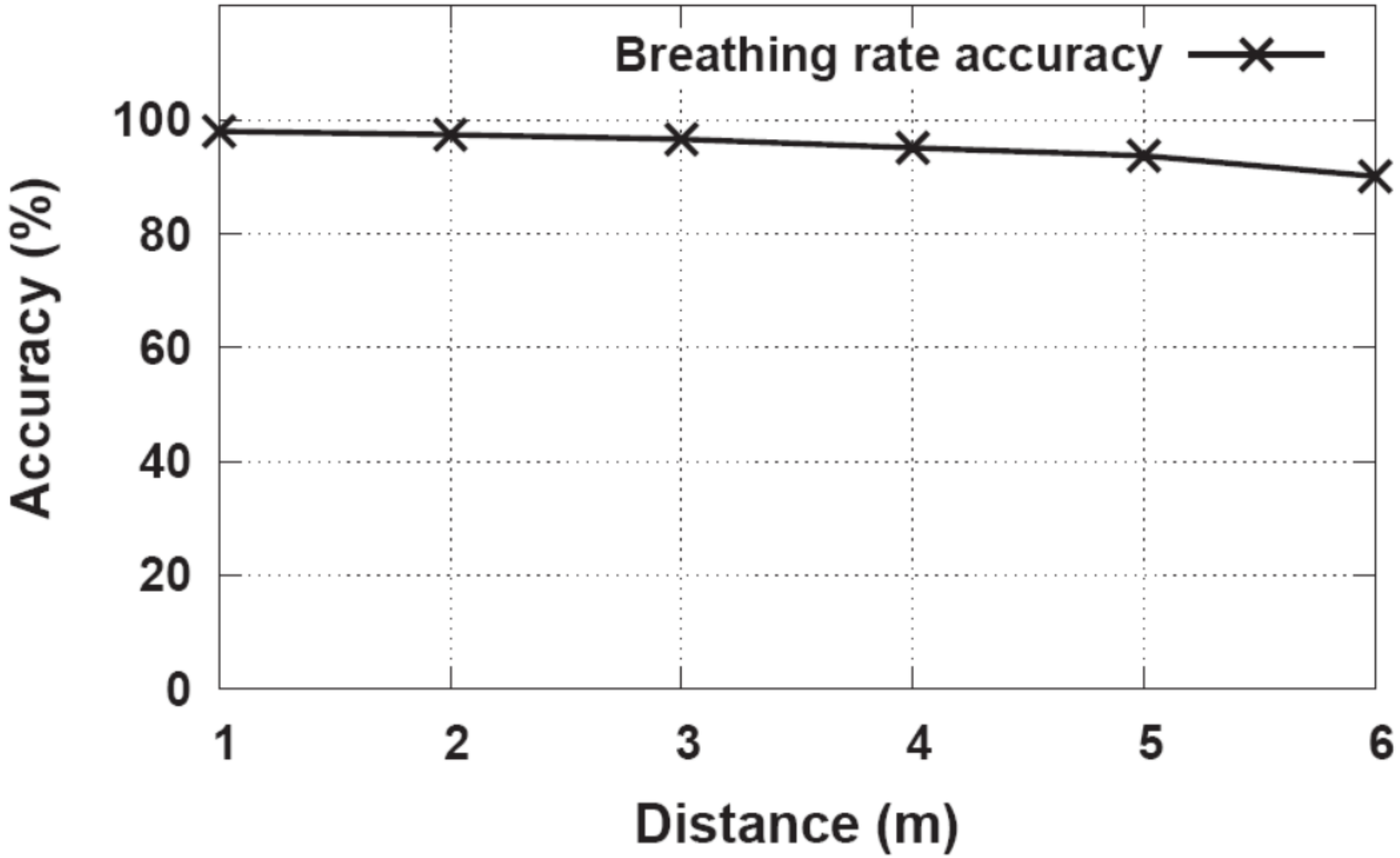
- **Default Configuration**

Table I
SYSTEM PARAMETERS AND DEFAULT EXPERIMENT SETTINGS

Parameter	Range	Default
Channel	channel 1 - channel 10	Hopping
Tx power	15 - 30 dBm	30 dBm
Distance	1m - 6m	4m
Orientation	0° (front) - 180° (back)	front
Number of users	1 - 4 users	1 user
Tags per user	1 - 3 tags	3 tags
Breathing rate	5 - 20 bpm	10 bpm
Posture	Sitting, Standing, Lying	Sitting
Propagation path	with/without LOS path	with LOS path

Evaluation

- **Evaluation Results**

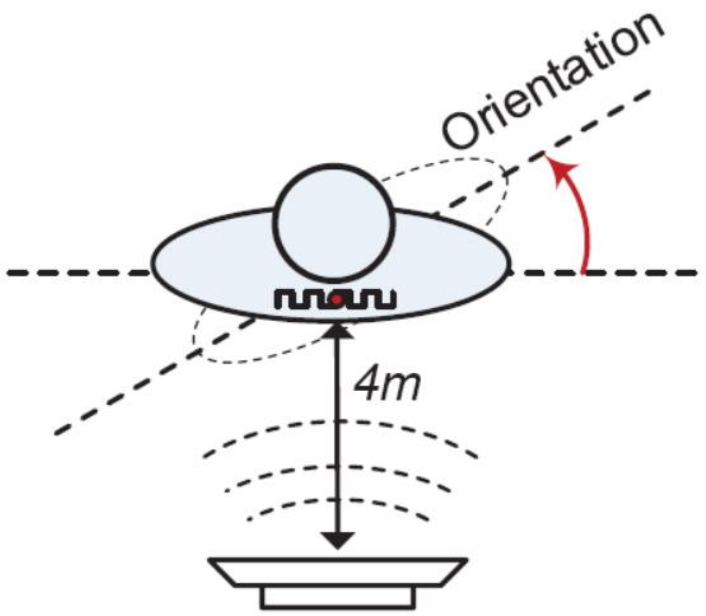


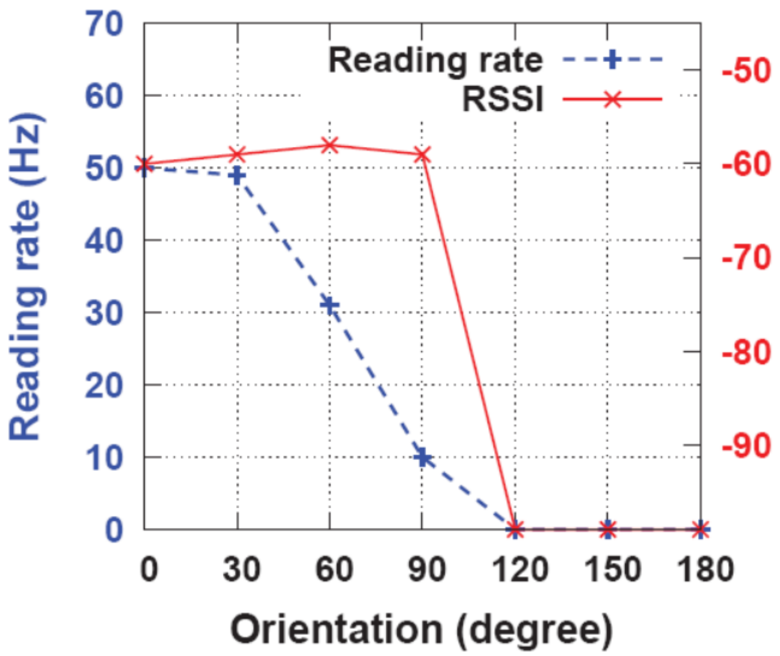
Breathing rate accuracy at different **distances**.

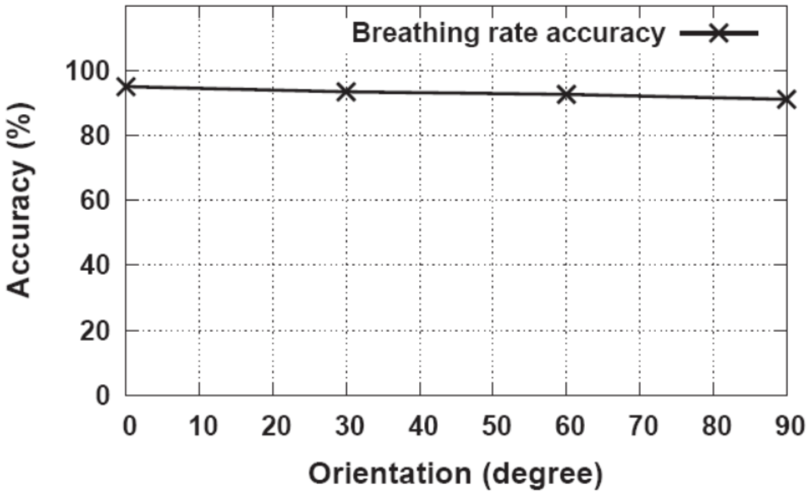
- The breathing rates range from 5 to 20 breaths per minute (bpm).
- Repeat the experiments for 100 times
- Each experiment lasts for two minutes.

Evaluation

- **Evaluation Results**



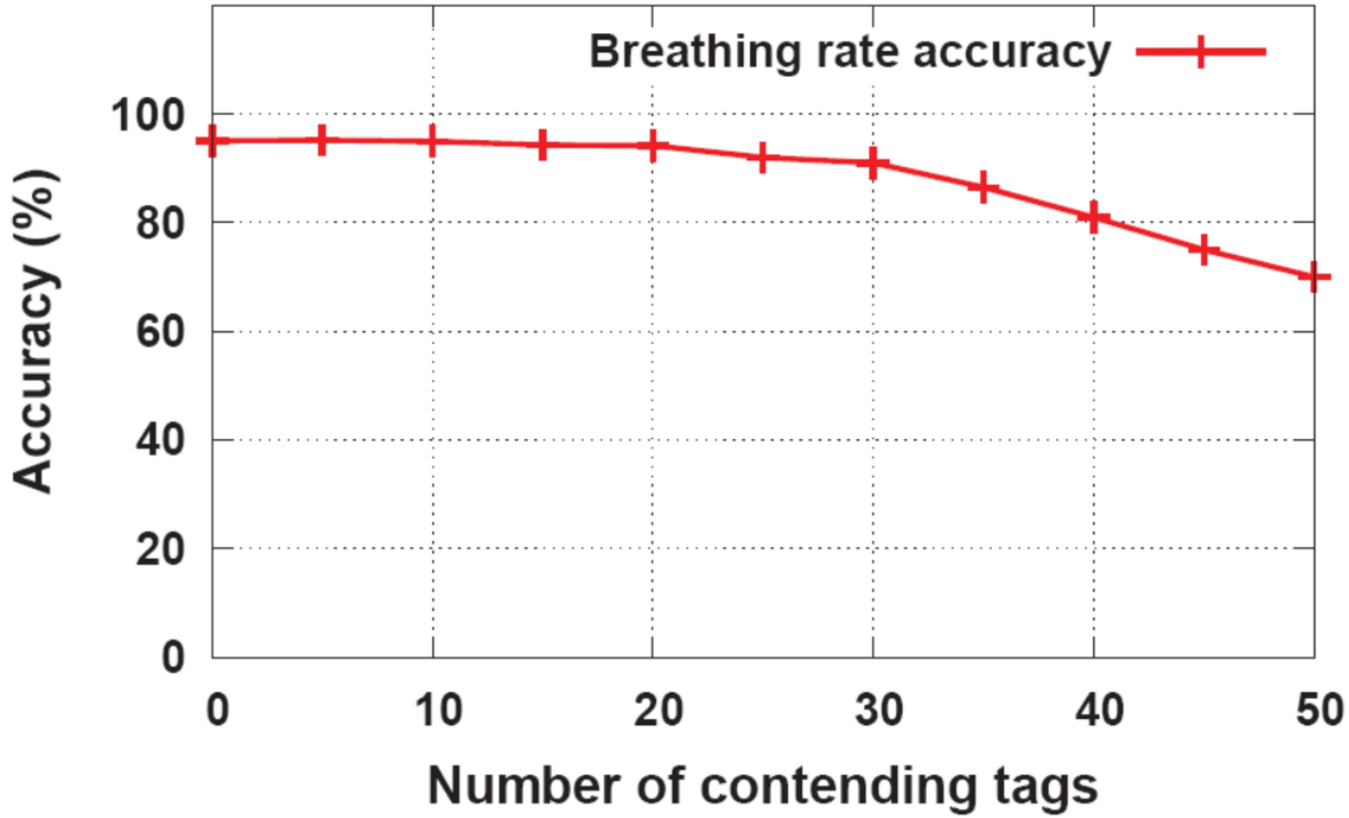




Reading rate and RSSI in different **orientation and accuracy.**

Evaluation

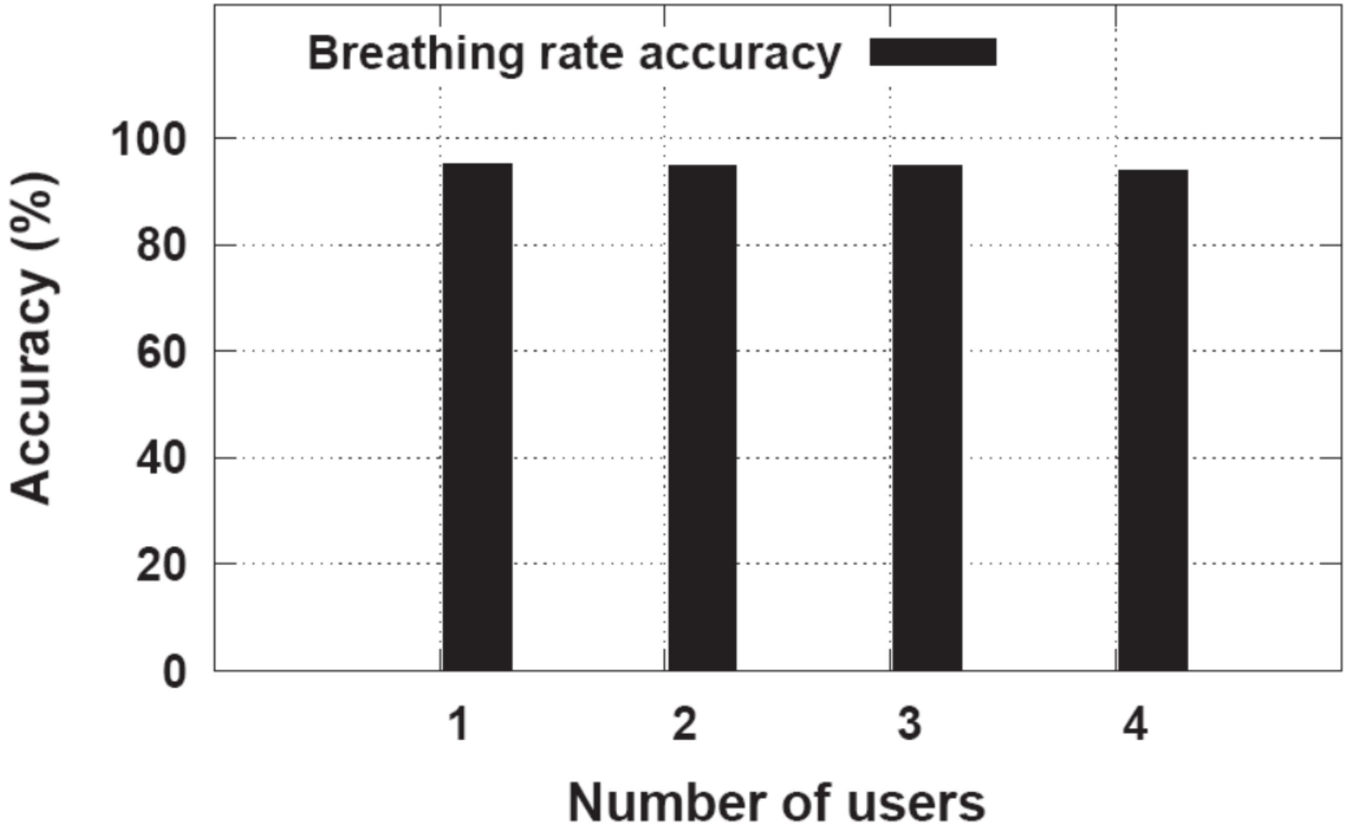
- **Evaluation Results**



Breathing rate accuracy with different **# of tags.**

Evaluation

- **Evaluation Results**



Breathing rate accuracy with different **# of users**.

Conclusion

- We propose a low cost, non-intrusive COTS RFID system to monitor human breath.
- We carefully design sensor fusing algorithms to extract breathing signals from the low level data reported by commodity readers.
- *TagBreathe* can monitor breathing for multiple users

Thanks!