GPSense: Passive Sensing with Pervasive GPS Signals

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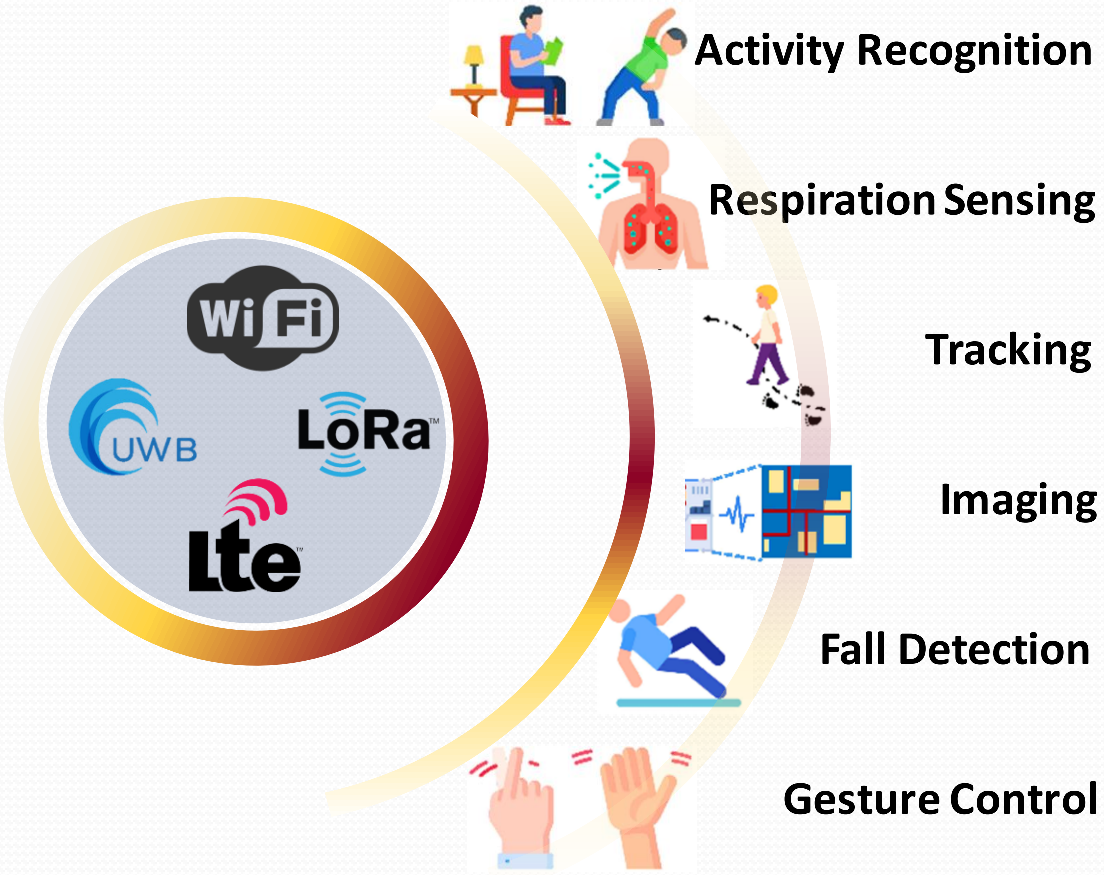
Sensing with pervasive wireless radios



Explosive growth of wireless sensing

Rescue

Smart Ranch

Automotive industry

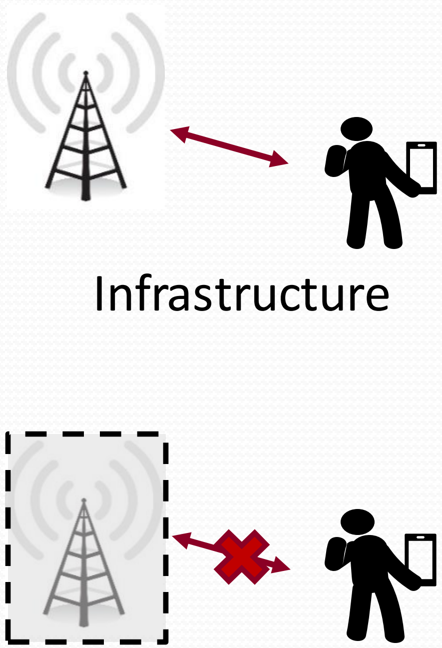
Smart Farm

Sensing with pervasive wireless signals are more **cost-effective** and **scalable**.

Limitations of Existing Wireless Sensing

Limitations of wireless sensing

1. Infrastructure shortage



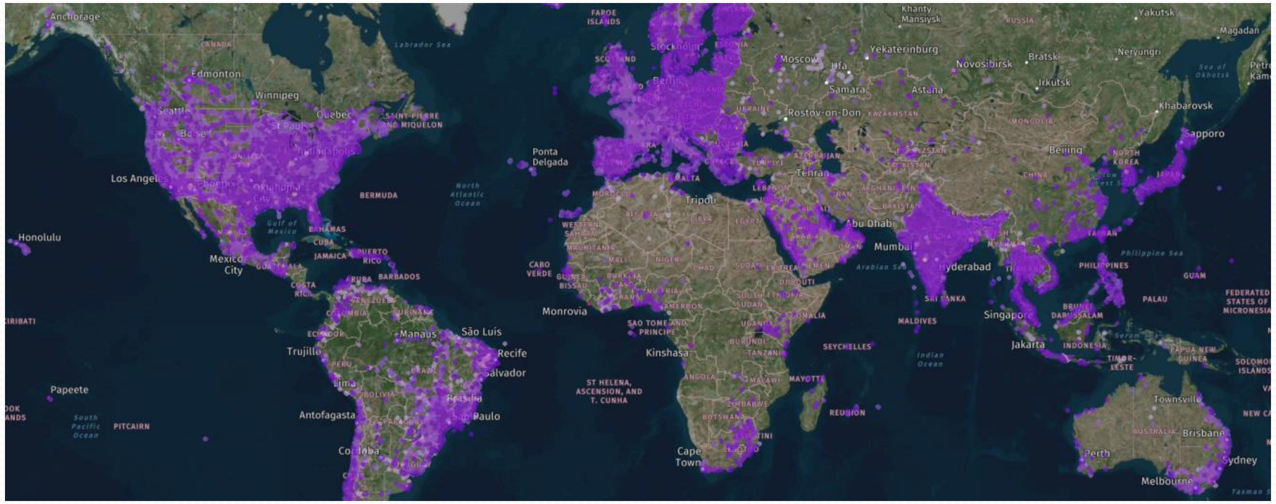
Can Sense

Infrastructure

Cannot Sense

No Infrastructure

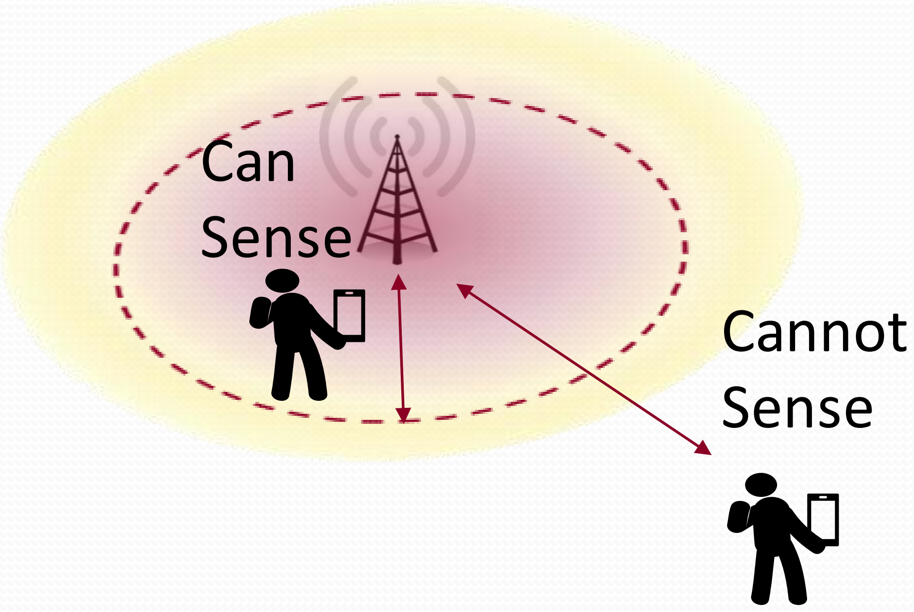
Existing wireless infrastructure is still not sufficient for pervasive wireless sensing



Realtime Global cellular network illustration. https://www.nperf.com/zh_CN/map/5g

Limitations of wireless sensing

2. Limited sensing coverage



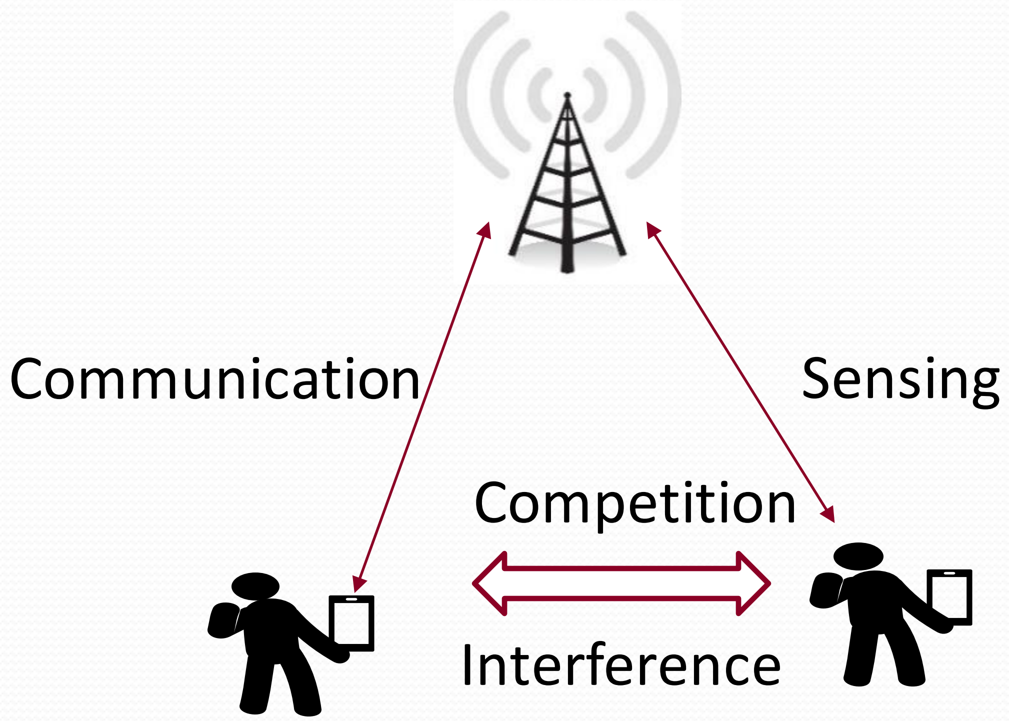
Performance degrades with increase distances

Coverage of existing wireless infrastructures

Infrastructures	Communication Range	Sensing Range
LTE Station (4G)	1-3 km	~100m
WiFi AP	50-100 m	~5-10m
LoRa Gateway	5-10 km	~100 m

Limitations of wireless sensing

3. Affect wireless communication



1 **Spectrum occupation**

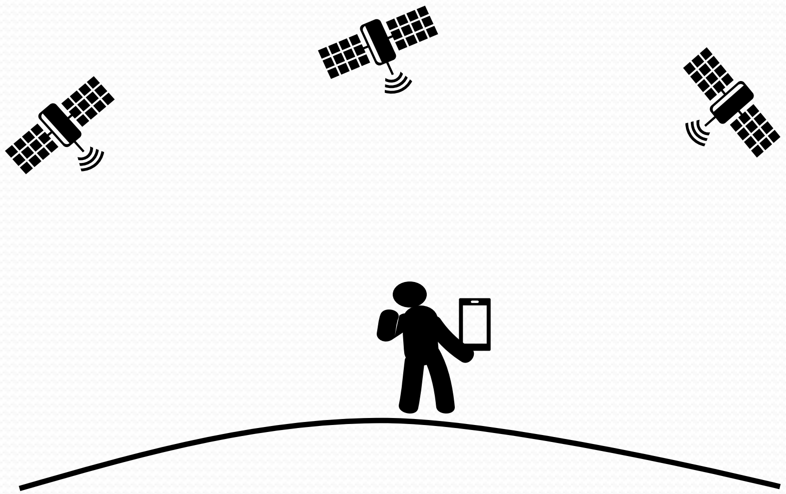
2 **Access competition**

3 **Interference**

Is there a new sensing modality that can utilize truly <u>Pervasive</u> signals for sensing without any <u>additional infrastructures</u>?

Our idea: Sensing with pervasive GPS signals

Sensing with pervasive GPS signals



Advantages of GPS signals

Large Coverage

One GPS satellite can cover **1/8 of the Earth** and 90% of areas can receive signals from at least **8** GPS satellites.

Easy Access

GPS signal is free for access at anywhere on Earth in **any time**.

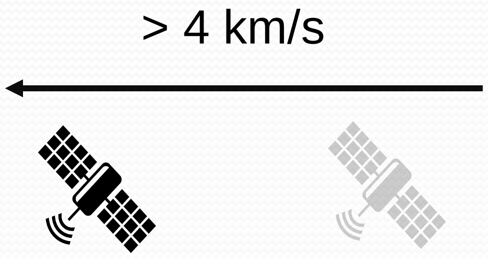
Dedicated Spectrum

GPS signals are transmitted in the dedicated spectrum, which brings them much lower noise floor than the signals in crowded ISM band.

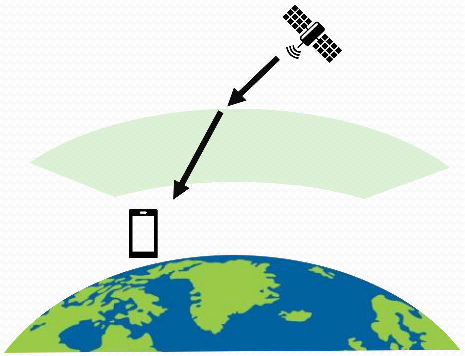
Challenges & Solutions

Challenge 1: Sensing information buried in measurements

Satellites Movements

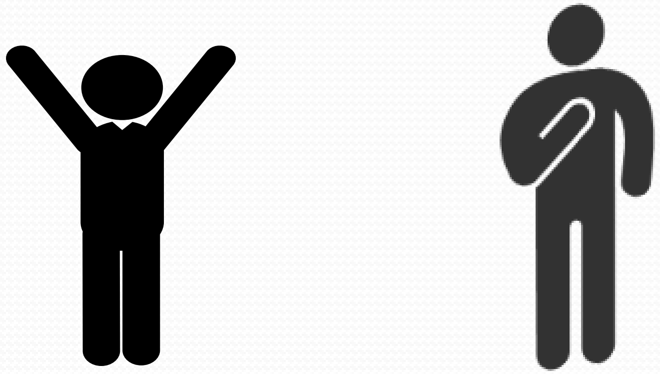


Atmospheric affects



VS

Human Activities

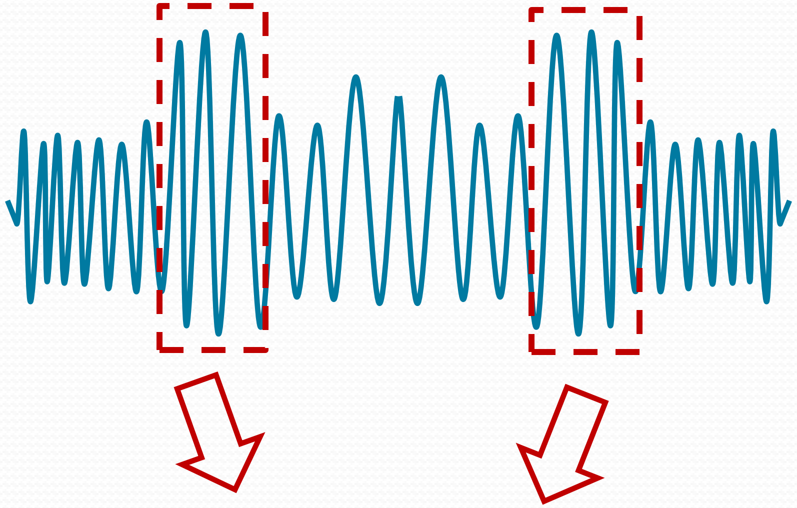


Kilometers-level changes

Meter/Decimal-level changes

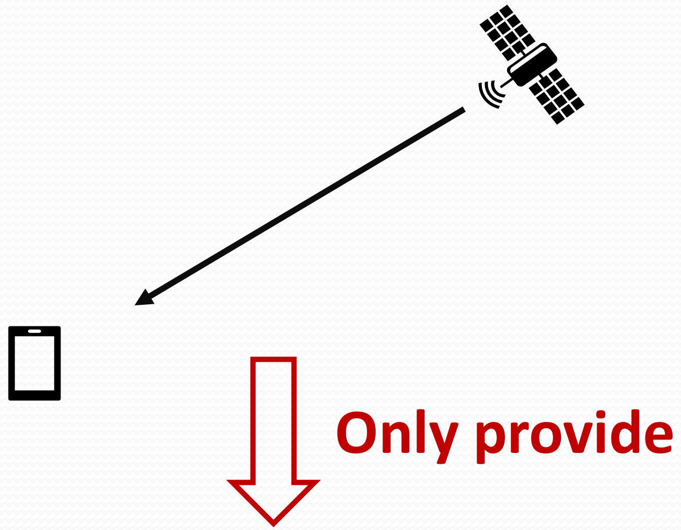
Challenge 1: Sensing information buried in measurements

Signal feature we need



Signals' phase and amplitude changes caused by targets

Processed signals in commercial GNSS sensor



Distance to the satellites (with error) and signal to noise ratio of the signal

Solution 1: Extract the relative change of targets

Key insight Analyze the relative instead of absolute changes of the signals

Step 1 Extract the relative changes by measurements differential.

Step 2 Reconstruct the raw amplitude and phases

Measurements differential → Error elimination

$$Amp(t) = \sqrt{P_n 10^{(C/N_0)/10}}$$

$$\phi(t) = \left(\frac{d\Phi}{\lambda dt} - \frac{2\pi f_D t}{\lambda}\right) + \frac{||\rho - ct_b||}{\lambda}$$

Challenge 2: Lack of sensing model

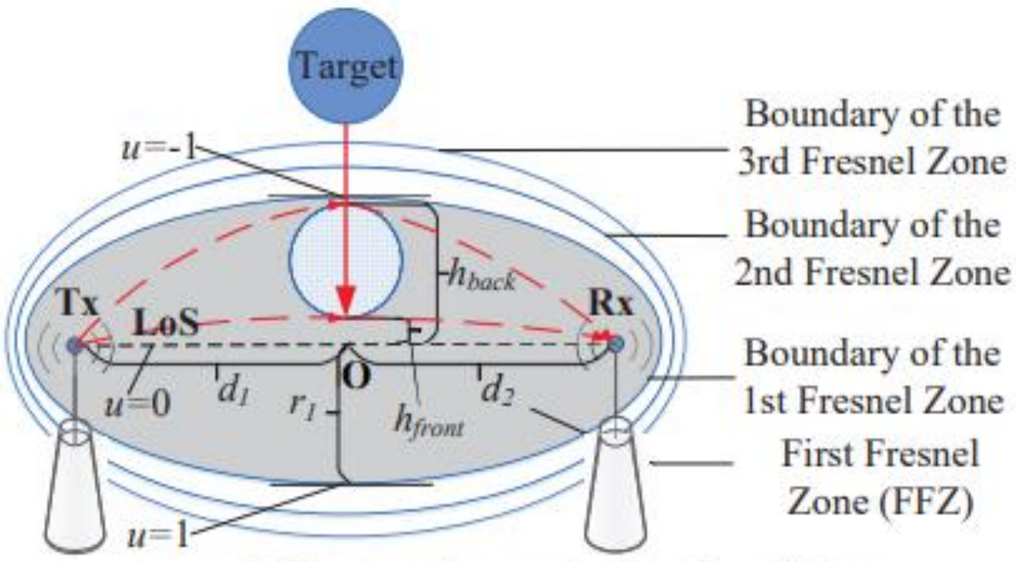
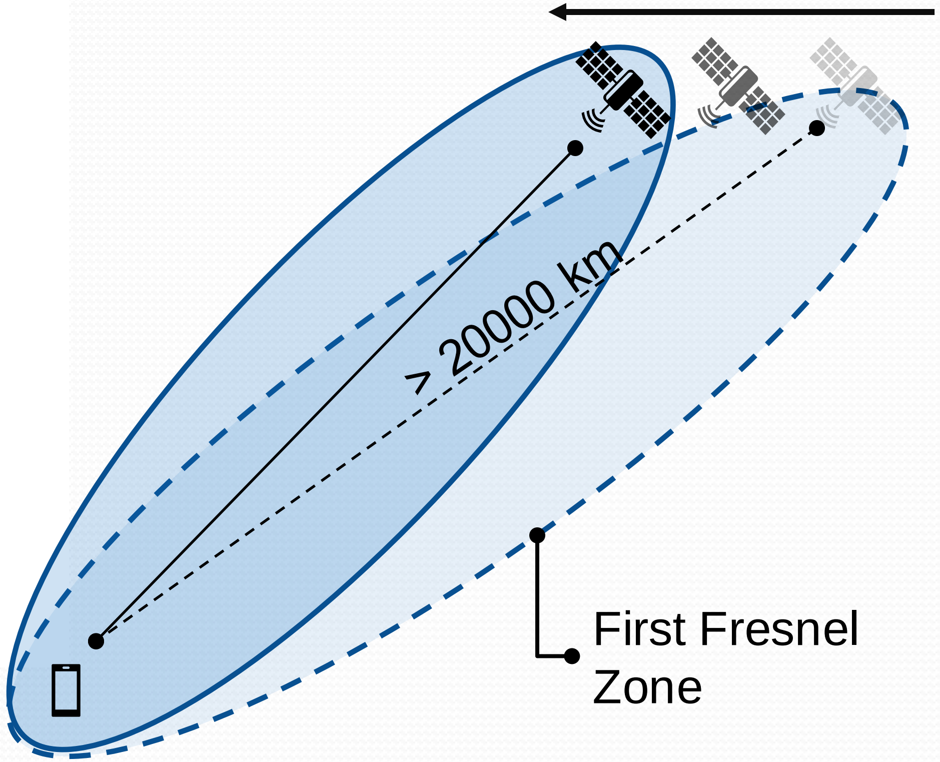


Fig. 4. Diffraction effects in the First Fresnel Zone.

[1] Towards a Diffraction-based Sensing Approach on Human Activity Recognition. Ubicomp 2019. Fusang Zhang, et al.



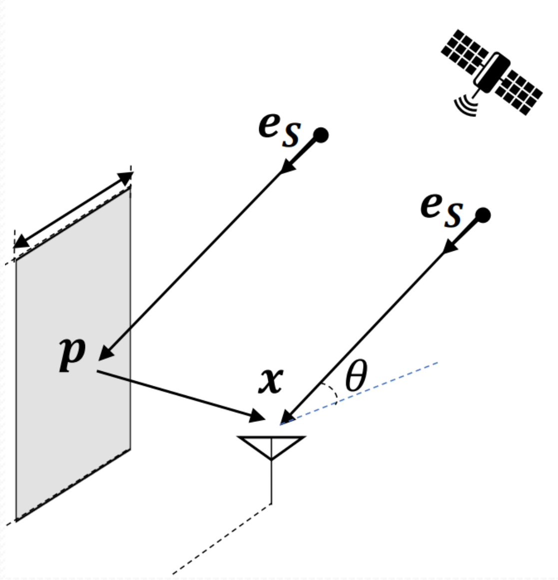
The First Fresnel Zone is hard to estimated with a rapid transmitter

Solution 2: GTD based sensing model

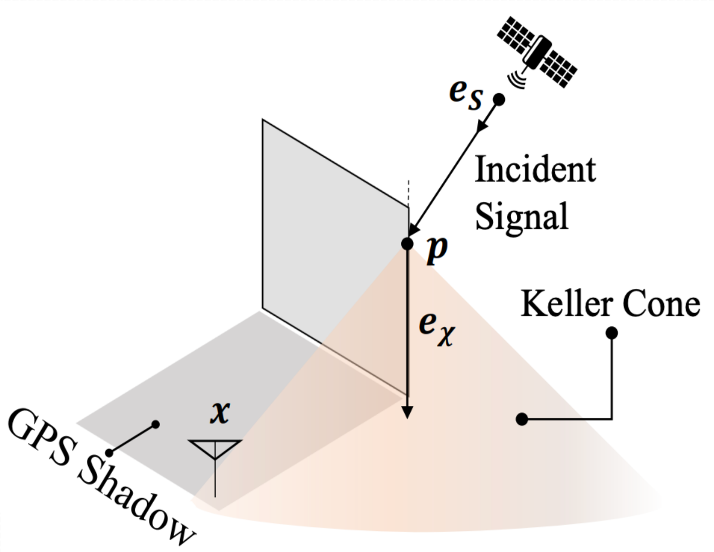
Key insight

GPS satellites are far away from the receiver → **Similar to a bunch of incident parallel light.**

Geometrical theory of diffraction and reflection



Signal reflected

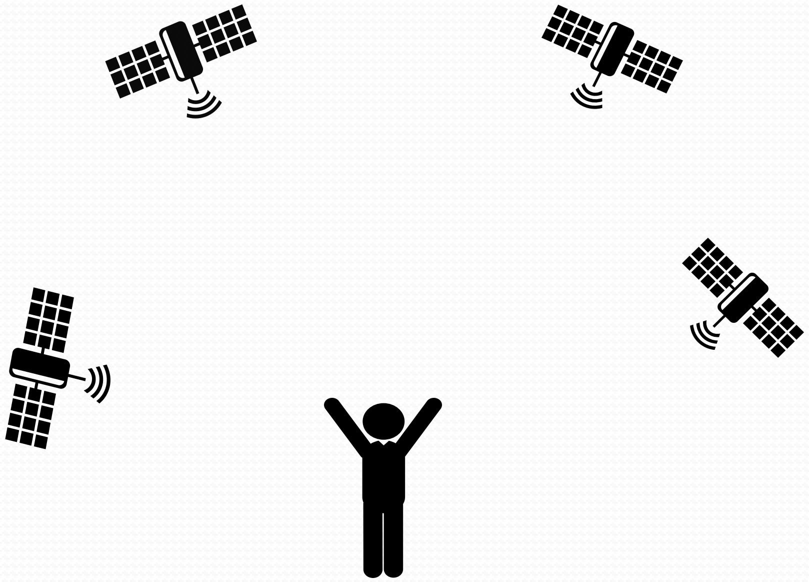


Signal diffracted

$$S_{Reflect}(\mathbf{x},\mathbf{p}) = \frac{\sqrt{P_s}}{4\pi||\mathbf{x}-\mathbf{p}||^2} e^{j\phi + j2\pi(||(\mathbf{x}-\mathbf{p})\cdot\mathbf{e}_s|| + ||\mathbf{x}-\mathbf{p}||)/\lambda},$$

$$S_{cone}(\mathbf{x},\mathbf{p},\mathbf{e}_\chi) = \frac{\sqrt{P_s} e^{j\phi + 2\pi((\mathbf{x}-\mathbf{p})\cdot\mathbf{e}_s + ||\mathbf{x}-\mathbf{p}||/\lambda)}}{2\pi\sqrt{1-||\mathbf{e}_s\cdot\mathbf{e}_\chi||^2}||\mathbf{x}-\mathbf{p}||} I(\mathbf{p},\mathbf{e}_s,\mathbf{e}_\chi)$$

Challenge 3: Combining multiple satellites



Combine multiple distributed GPS satellites from different direction ?

Solution: Spatial combination of distributed satellites' signals.

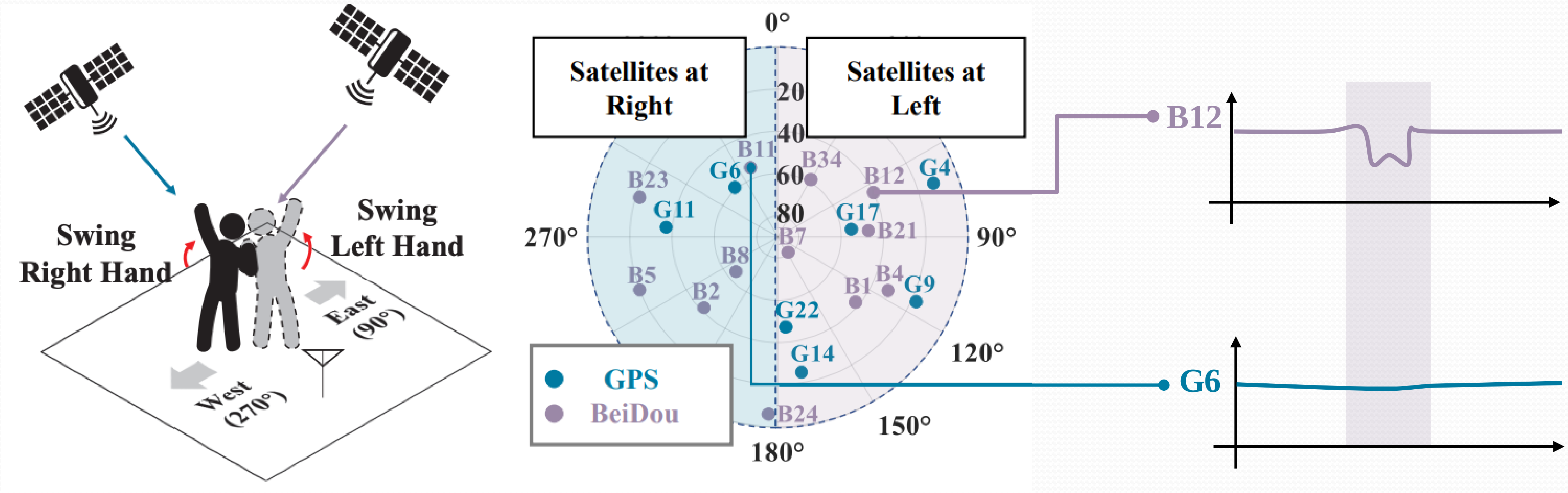
- Combination of satellites from different azimuth angles.
- Combination of satellites from different elevation angles.
- Combination of diffraction and reflection features.

→ **Spatial-weighted recognition algorithm**

Solution 3: Spatial-weighted recognition algorithm

Combination of satellites from different azimuth angles.

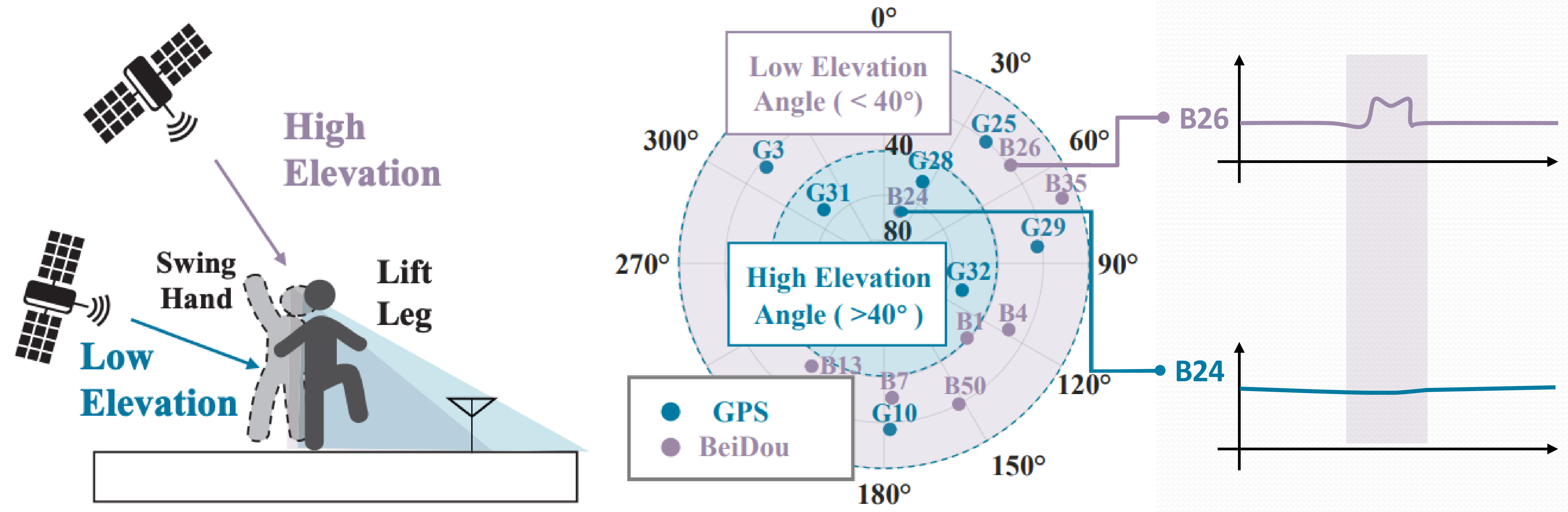
More significant variance from satellite at left



Solution 3: Spatial-weighted recognition algorithm

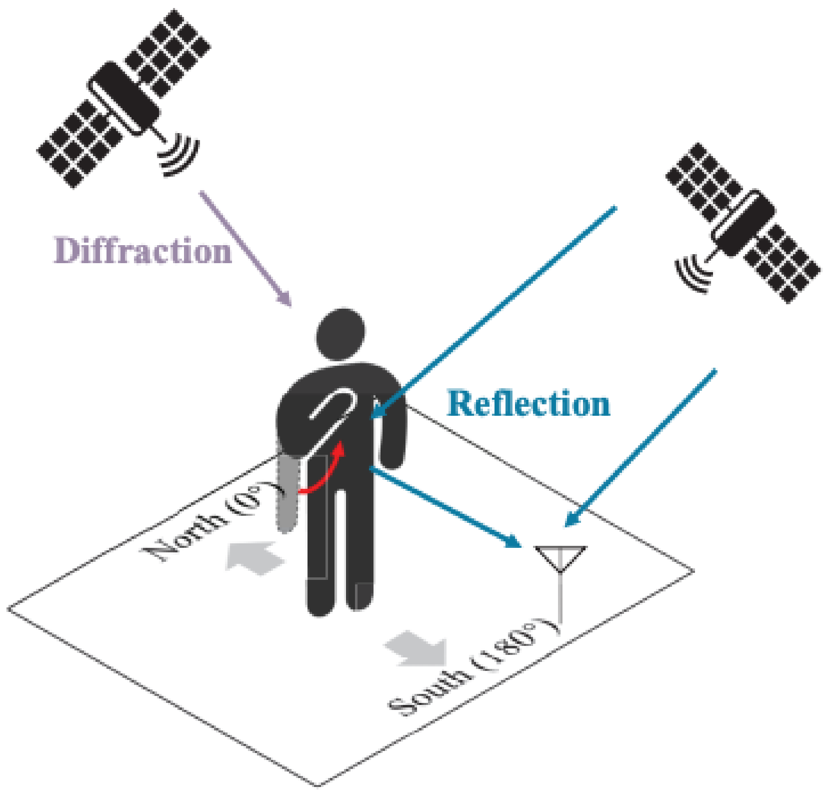
Combination of satellites from different elevation angles.

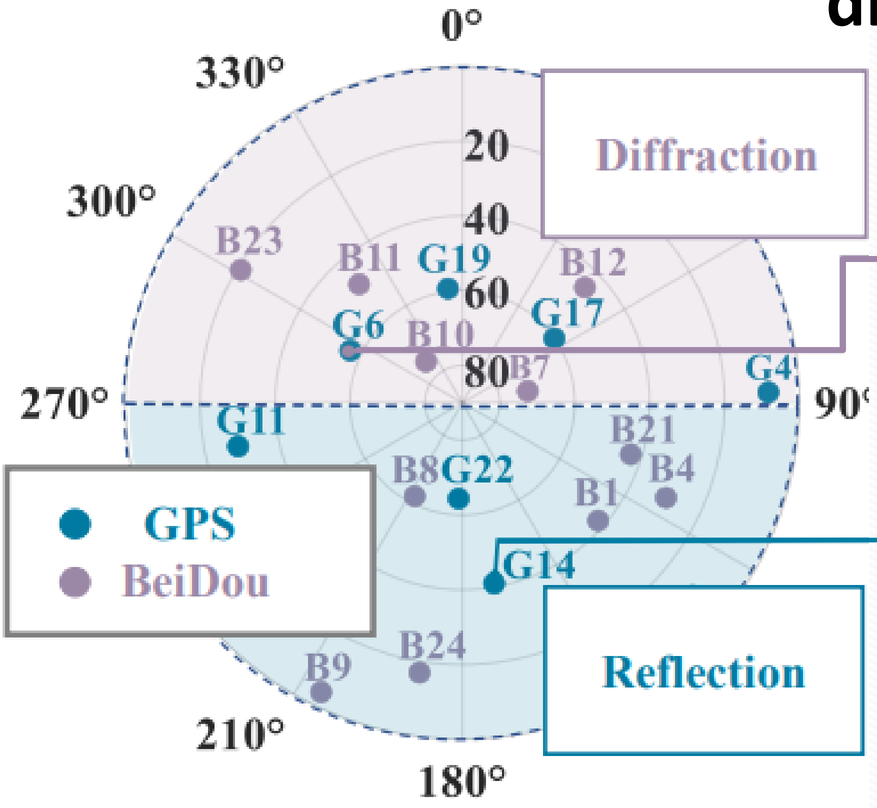
More significant changes from satellite at low elevation



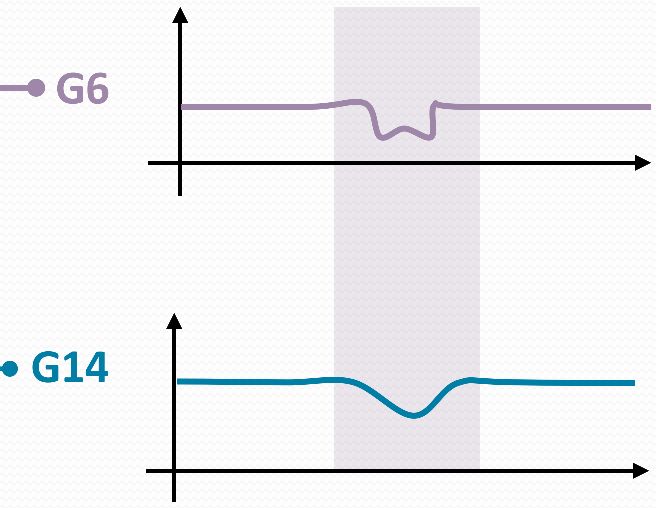
Solution 3: Spatial-weighted recognition algorithm

Combination of diffraction and reflection sensing model.

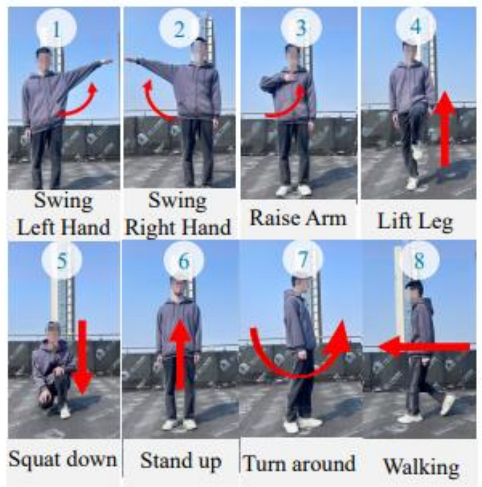




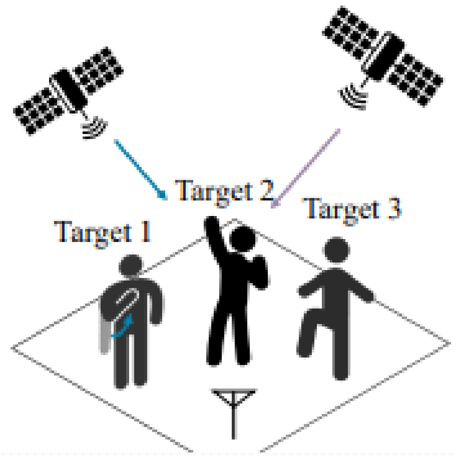
Different reflection and diffraction features

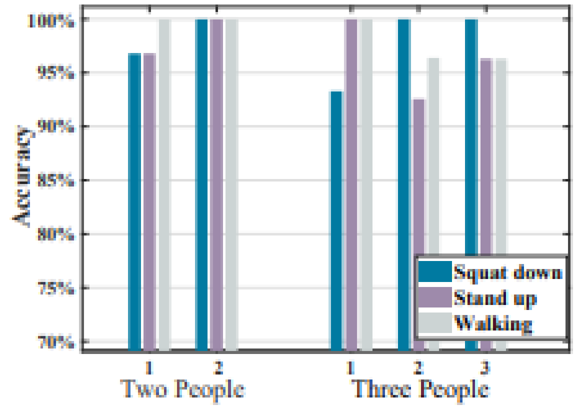


Human activity recognition with GPS signals



True Class \ Classified Class	1	2	3	4	5	6	7	8
1	94.1%	5.9%						
2	2.8%	97.2%						
3			100%					
4				100%				
5					98.3%		1.7%	
6						96.6%	3.4%	
7					3.4%		95.6%	
8					1.6%			98.4%

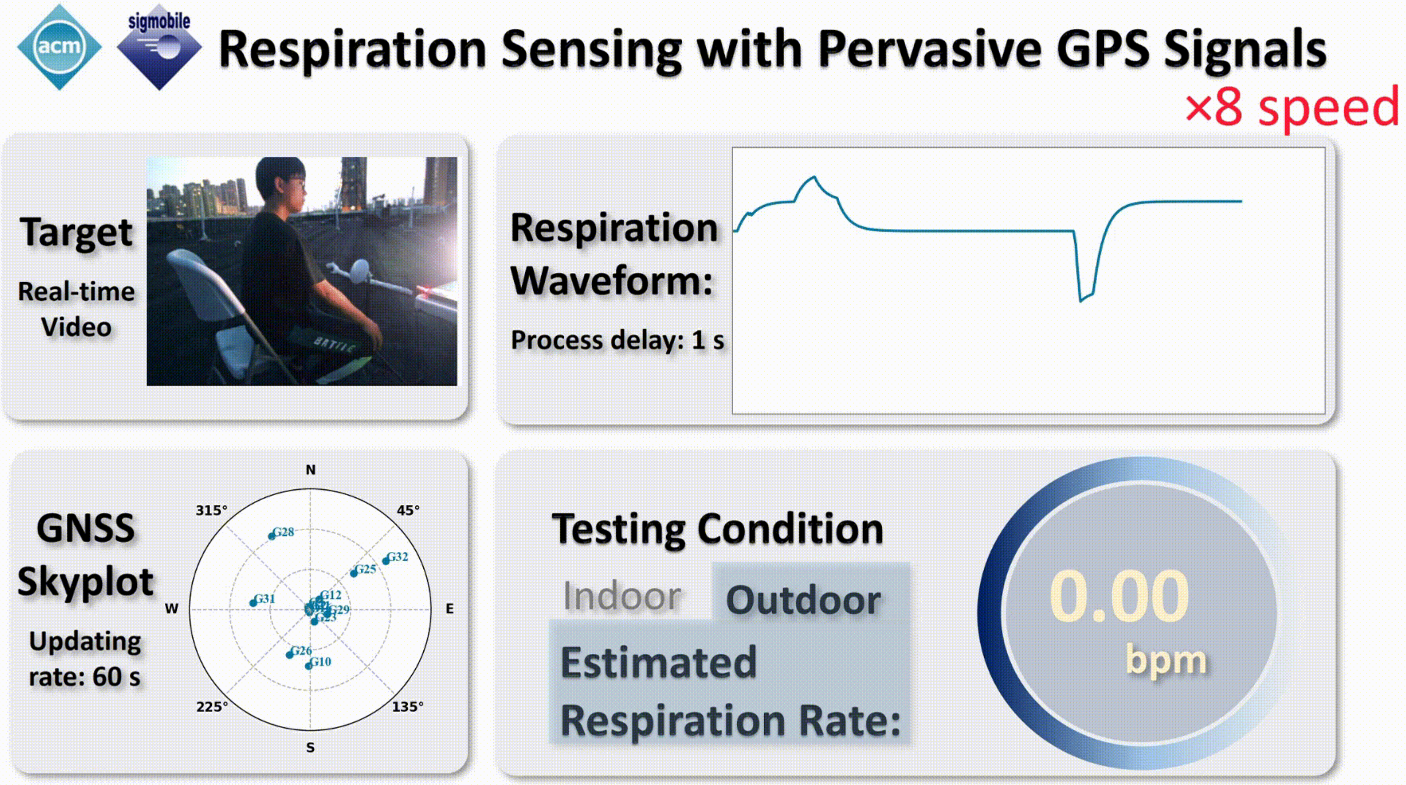




97.5% accuracy in single target condition

97.2% accuracy in multiple targets condition

Respiration sensing with GPS signals



More details please refer to our paper

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Respiration sensing error less than 0.6 beats per minutes (bpm).

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Thanks!