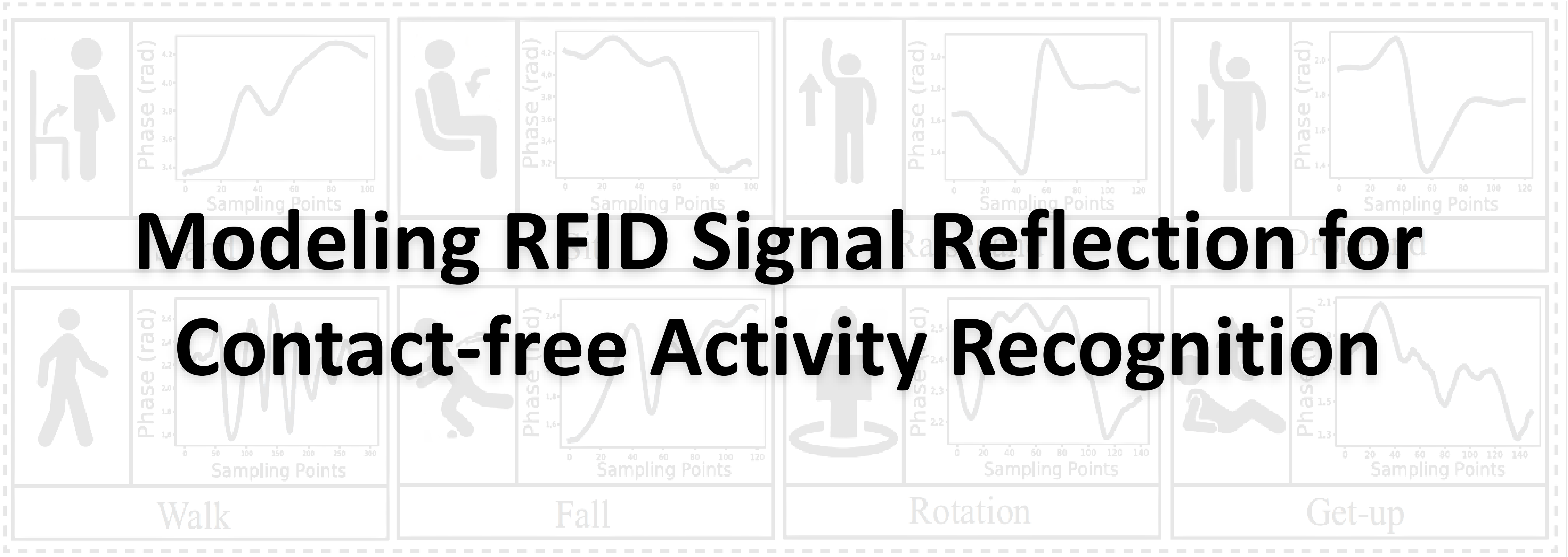

Modeling RFID Signal Reflection for Contact-free Activity Recognition

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The Hong Kong Polytechnic University, Hong Kong, China

UbiComp 2019, London
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CONTENTS

01 **Introduction**

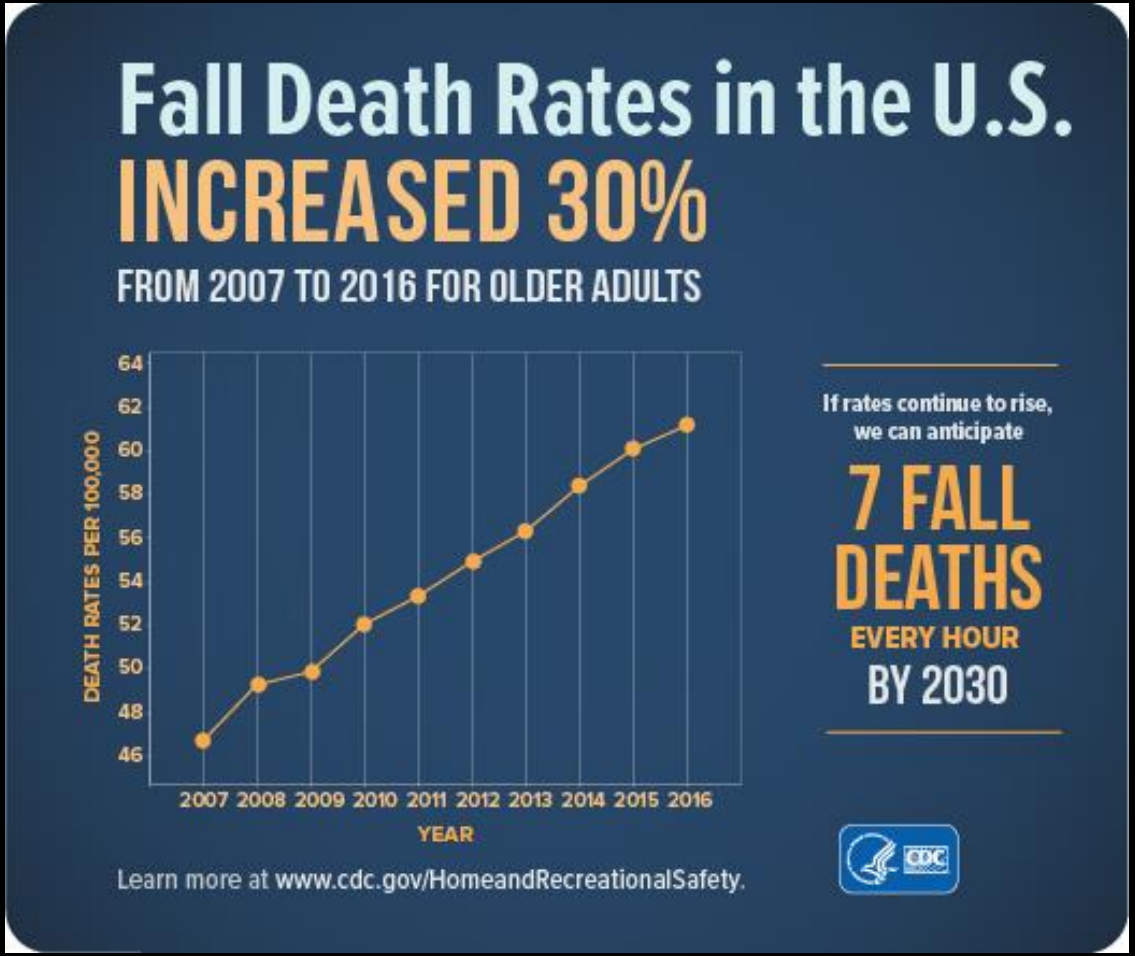
Human Activity Recognition necessity

◆ Falls Are Serious and Costly

•Each year, 3 million older people are treated in emergency departments for fall injuries.

•Over 800,000 patients a year are hospitalized because of a fall injury.

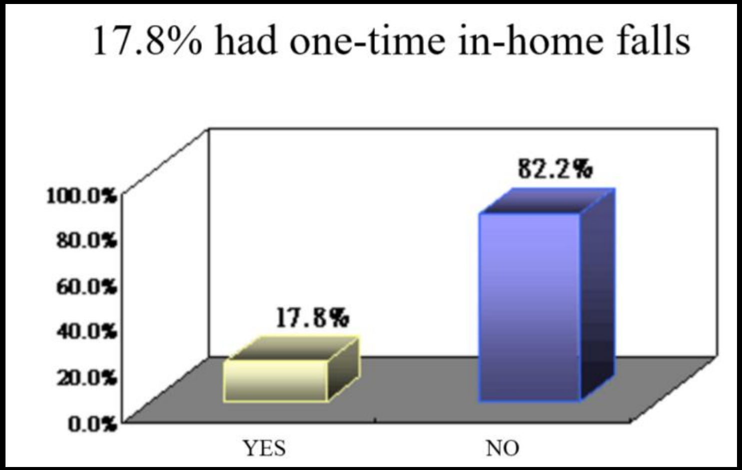
•Falls are the most common cause of traumatic brain injuries (TBI).

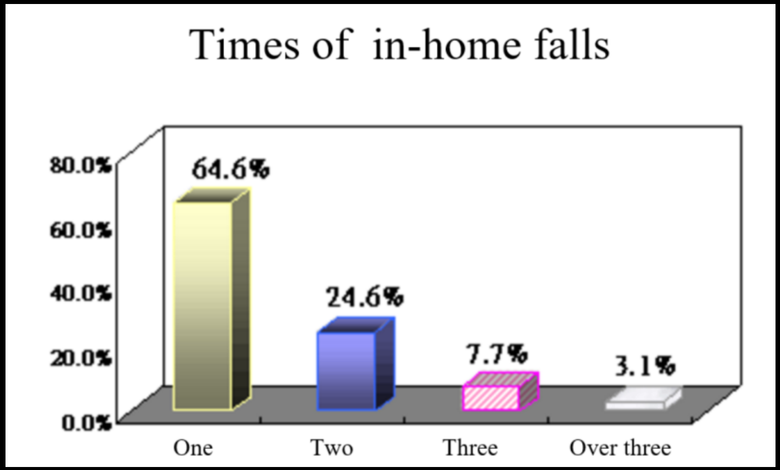


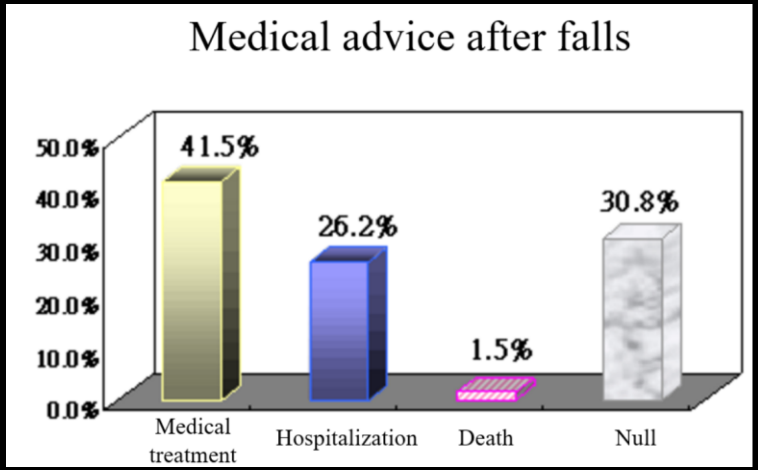
Bergen G, Stevens MR, Burns ER. Falls and Fall Injuries Among Adults Aged ≥65 Years — United States, 2018. MMWR Morb Mortal Wkly Rep 2016; 65:993–998. DOI: http://dx.doi.org/10.15585/mmwr.mm6537a2

Human Activity Recognition necessity

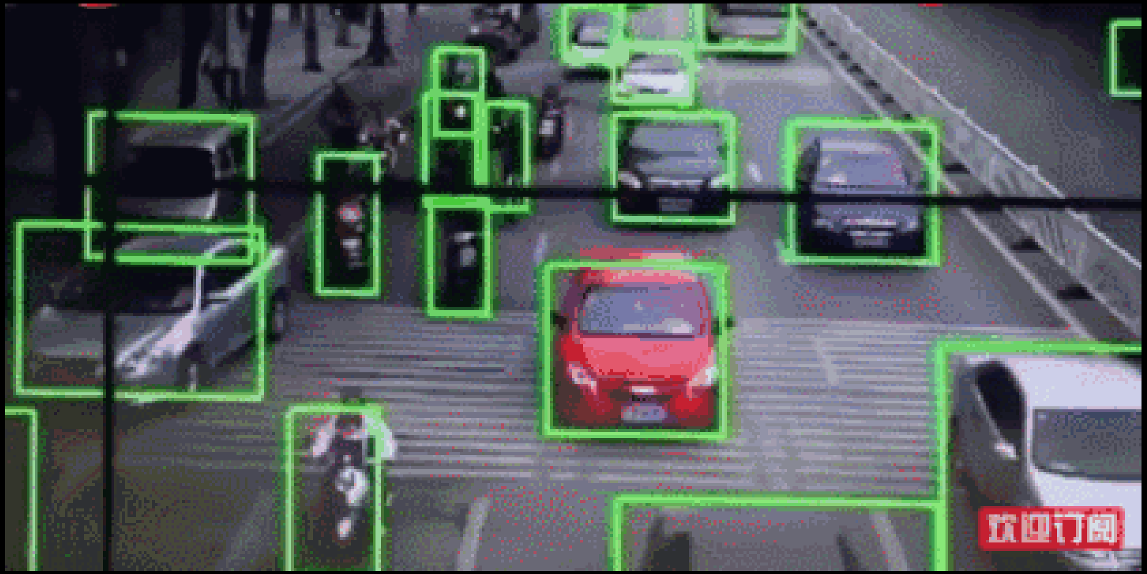
- 17.8% had one-time in-home falls
- Post fall medical outpatient was 41.5%
- 50% of the citizens do not deploy any preventive equipment at home







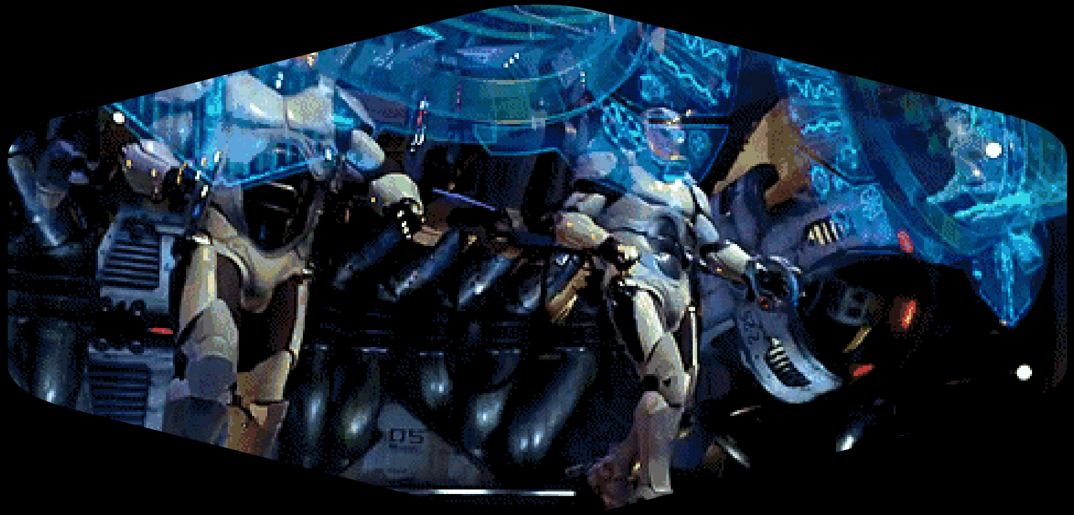
Camera-based Activity Recognition



[1] Fang, Biyi, Xiao Zeng, and Mi Zhang. "Nestdnn: Resource-aware multi-tenant on-device deep learning for continuous mobile vision." In ACM MobiCom, 2018.
[2] Xu, Mengwei, et al. "DeepCache: principled cache for mobile deep vision." Proceedings of the 24th Annual International Conference on Mobile Computing and Networking. ACM, 2018.

Privacy concern, LoS dependent

Wearable sensor-based Activity Recognition



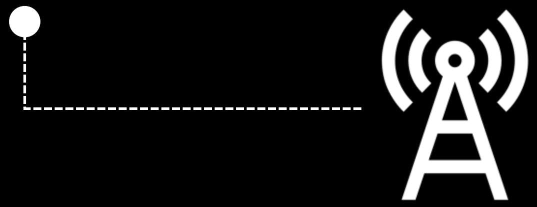
[1] Han Ding, Longfei Shangguan, Zheng Yang, Jinsong Han, Zimu Zhou, Panlong Yang, Wei Xi, and Jizhong Zhao. Femo: A platform for free-weight exercise monitoring with rfids. In ACM SenSys, 2015.
[2] Yuxiao Hou, Yanwen Wang, and Yuanqing Zheng. TagBreathe: Monitor Breathing with Commodity RFID Systems. In IEEE ICDCS, 2017.

- Direct body contact
- Inconvenience
- High cognitive load

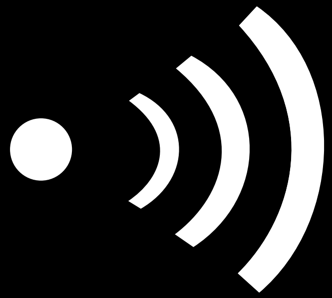
Wireless signal-based Activity Recognition

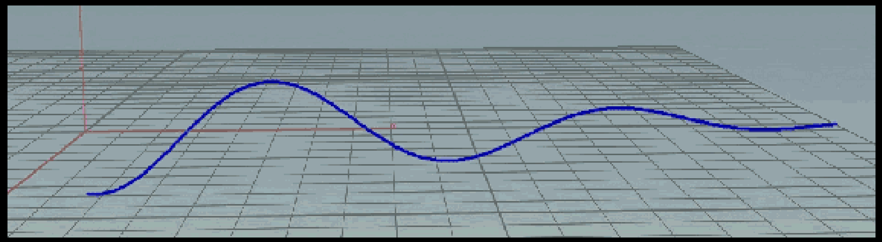
Wireless Signal

RF Signal



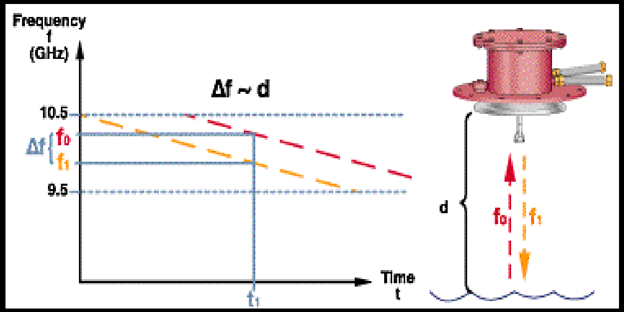
Transceiver

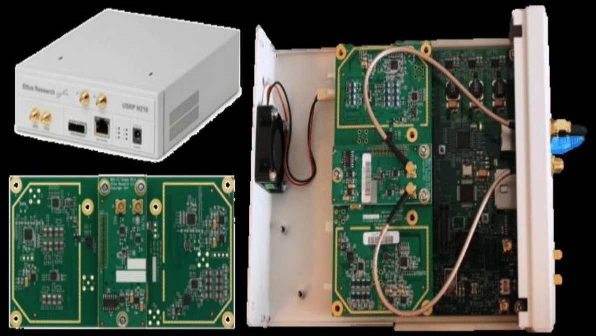




Phase

Wireless signal-based Activity Recognition





Wi-Fi	FMCW	USRP
Low resolution	Specialized devices High cost	Specialized devices High cost

- Low resolution
- High deployment cost

Camera

- X LoS
- X Privacy

Sensor

- X Intrusive
- X Direct contact

Wireless

- X High cost
- X Low resolution
- X Specialized devices

RFID

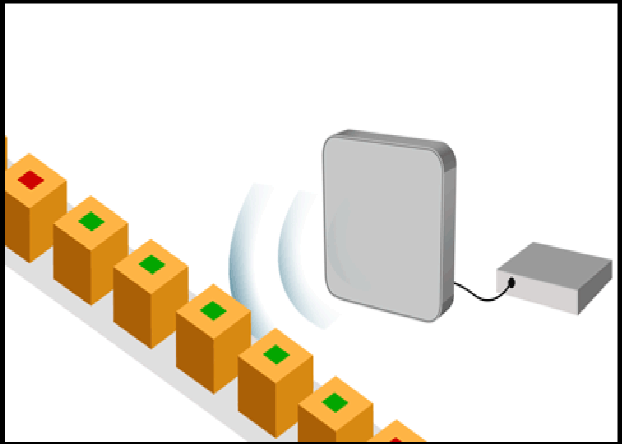
- √ Safe
- √ NLoS
- √ Convenient
- √ Contact free
- √ Non-intrusive

RFID

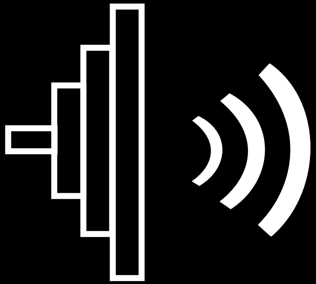
Contact-free

Signal reflection model

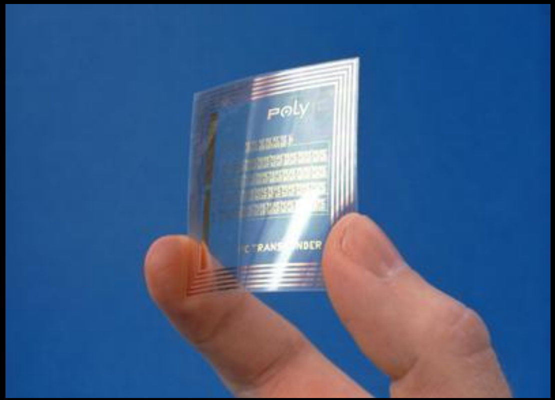
RFID System

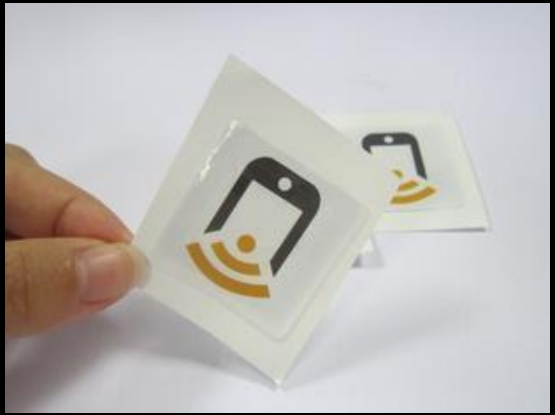


Reader

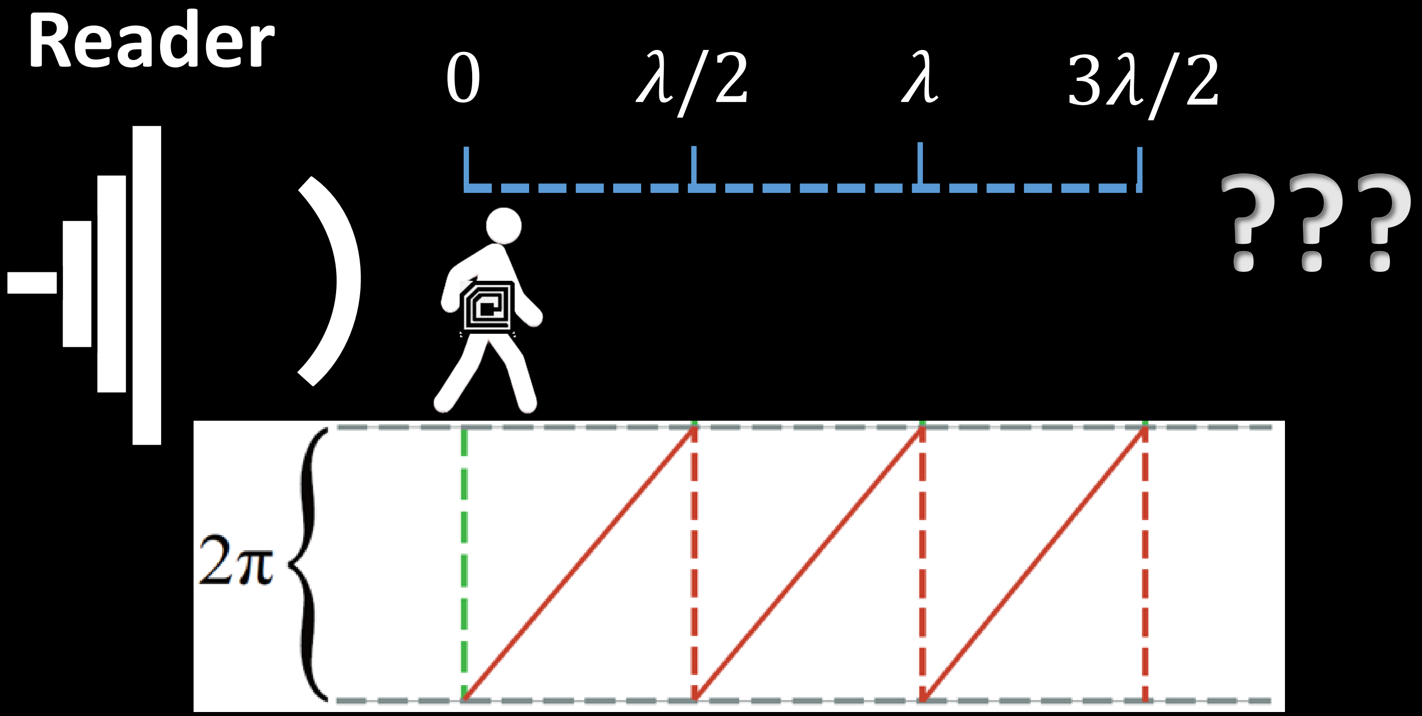


Tag





02 Methodology

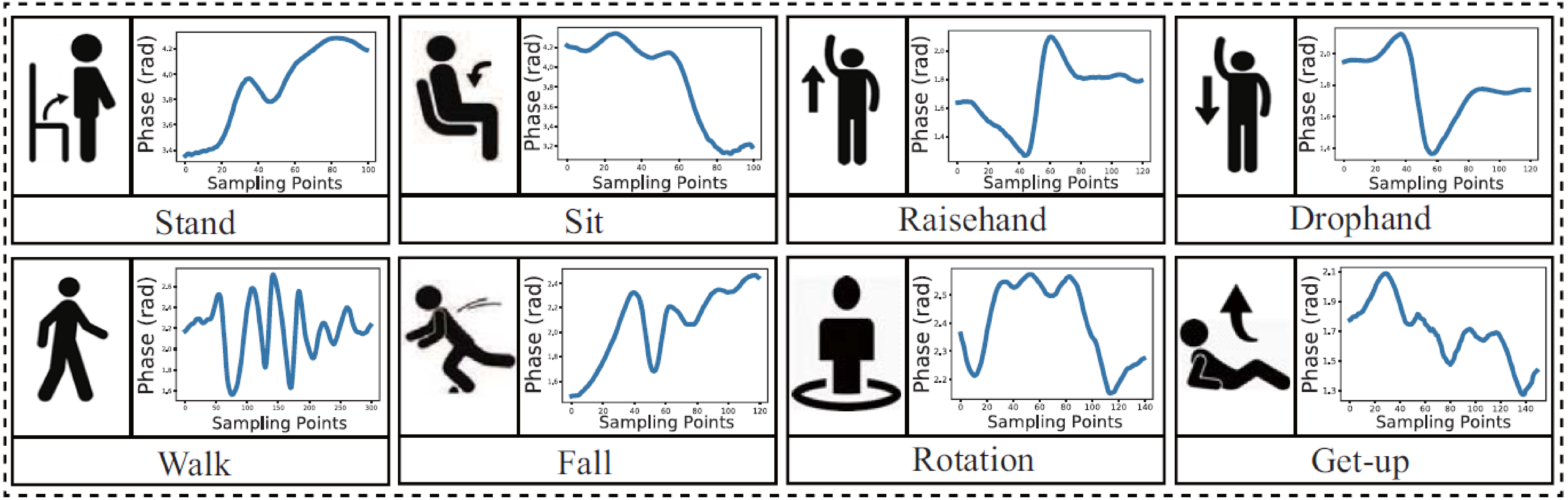


Phase change of the signal

- If the signal propagation distance changes continuously, the signal phase will change from [0,2π]
- If the signal propagation distance changes one wavelength, the signal phase will change 2π

If RFID tags are attached on human body (clothes), one may infer the type of human activity

Contact-free Activity Recognition
-----The **TACT** System

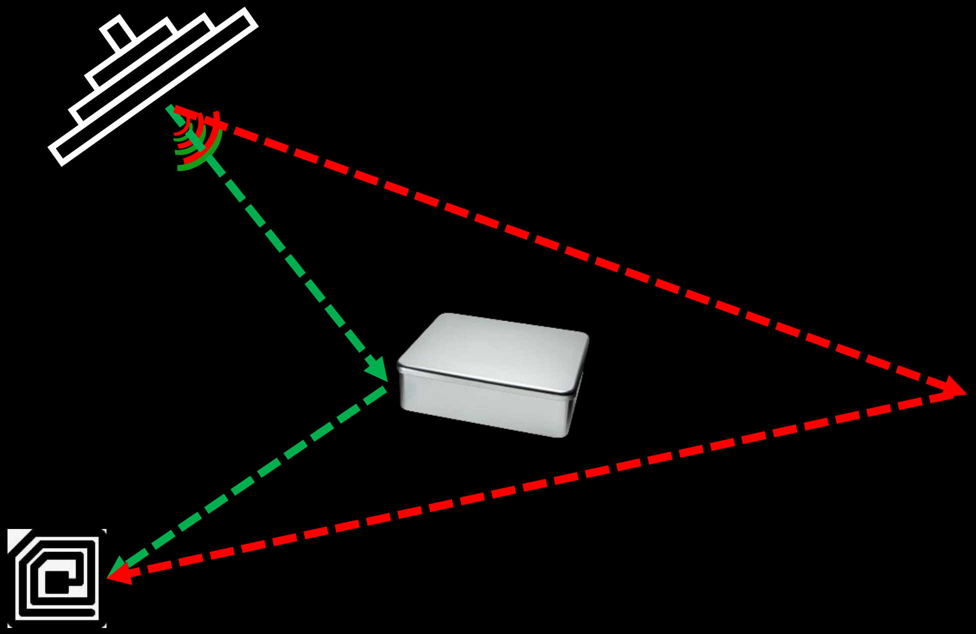


Reflection model for contact-free activity recognition

Understanding the Reflection of RFID Signal

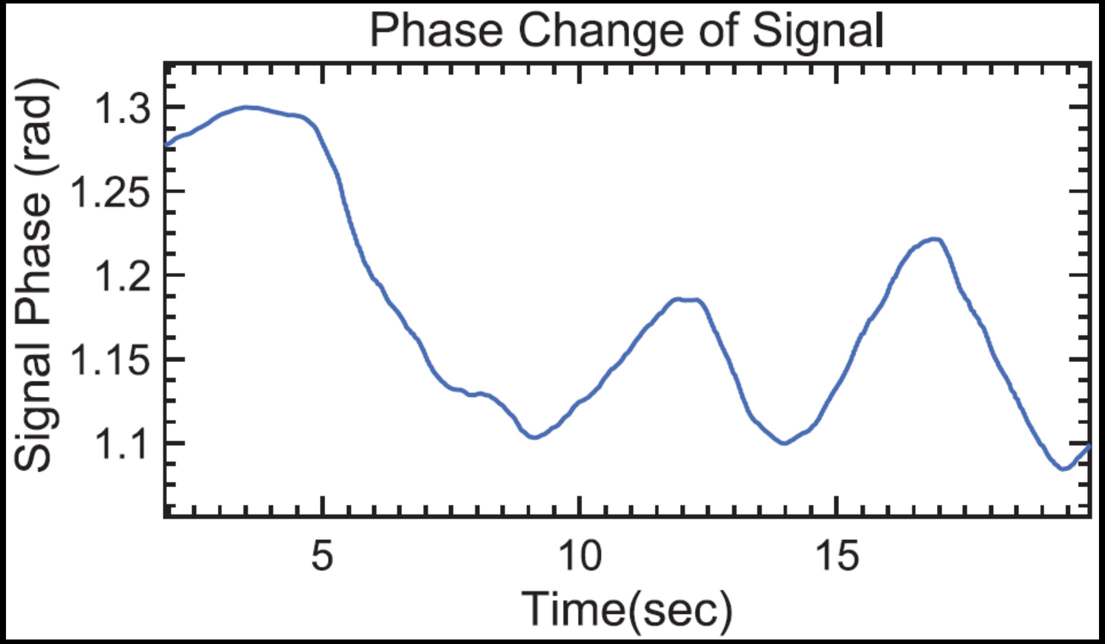
- **Preliminary experiments**

motionless reader



motionless tag

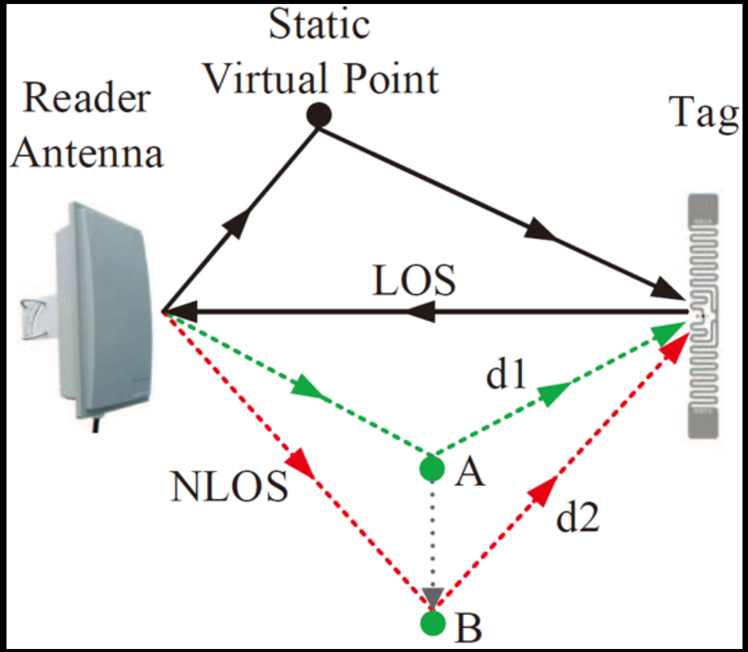
Signal propagation distance change

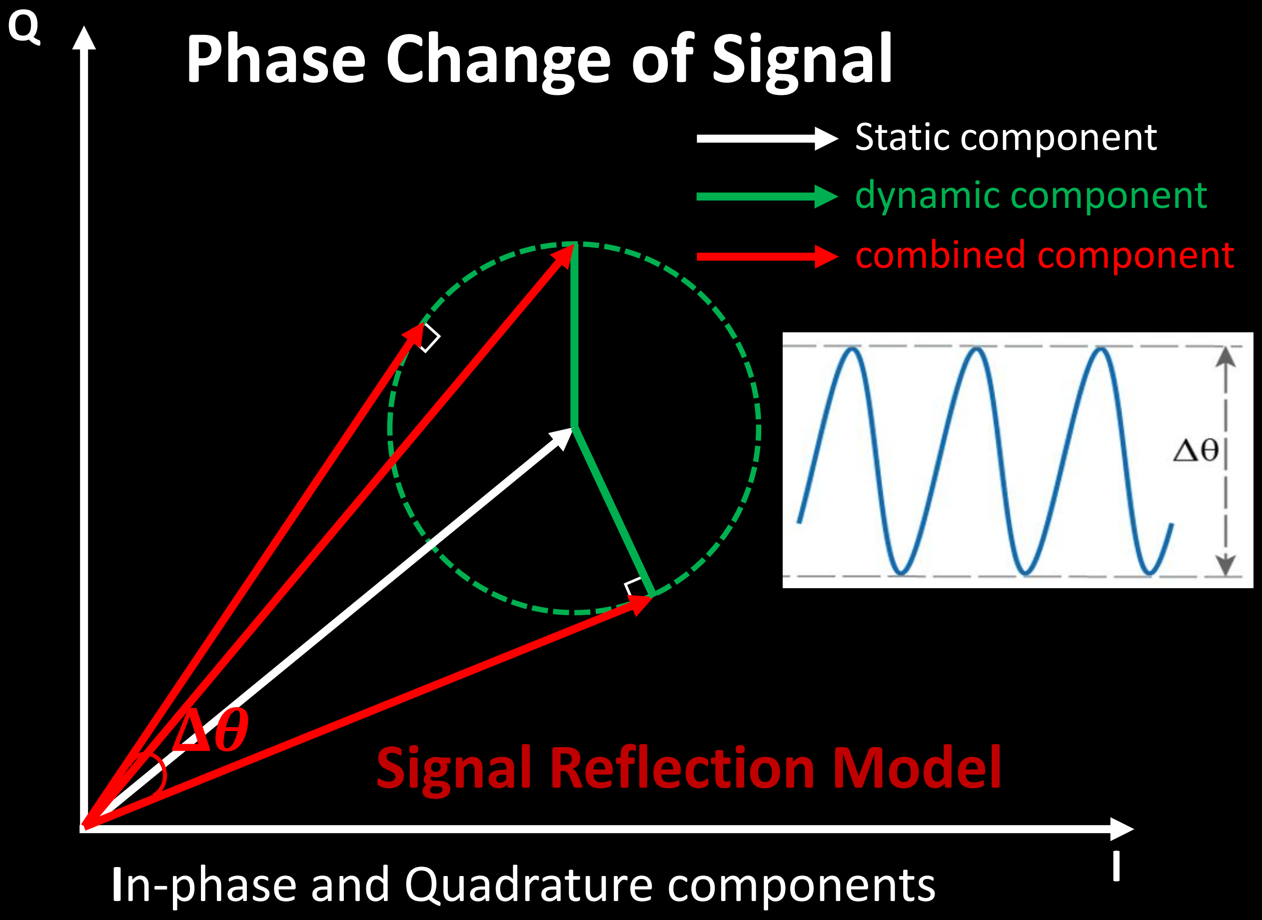


- ➢ **The phase values continuously changed and exhibited a periodic pattern.**
- ➢ **The range of phase values was only around 0.2, which was much smaller than 2π**

02 Methodology

Signal Reflection model



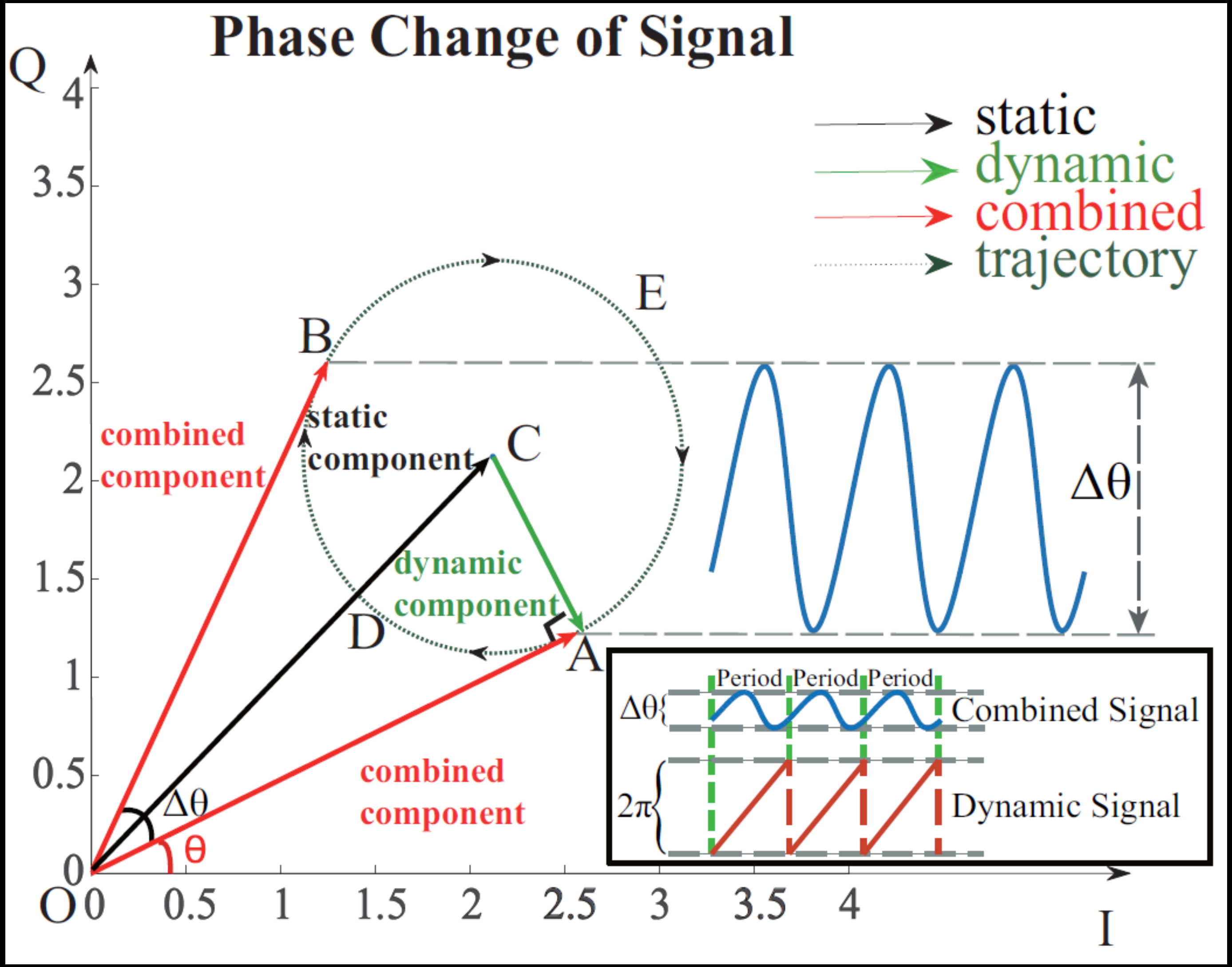


Static Virtual Point:
All the signal reflected from static objects & LoS

Object moving:
Moving from A to B

- When the object moves, the dynamic component rotates
- The combined phase reaches maximum and minimum at two tangent points
- The combined phase periodically changes
- The combined phase range is $\Delta\theta$

02 Methodology
Signal Reflection model



01 Signal phase $\in[\theta,\theta+\Delta\theta],\Delta\theta<2\pi$;

02 The phase waveform may not be a standard sinusoid form

03 Dynamic & Combined share same period

02 Methodology
Feature Extraction

Phase waveform

DTW

Time Duration

Variance

Speed

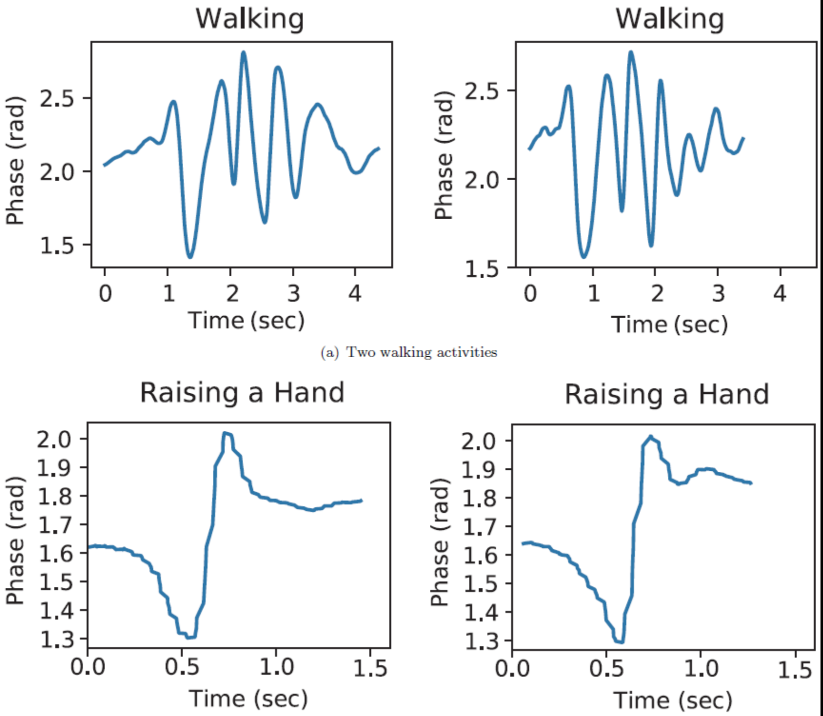
STFT

Distance

Phase difference

02 Methodology

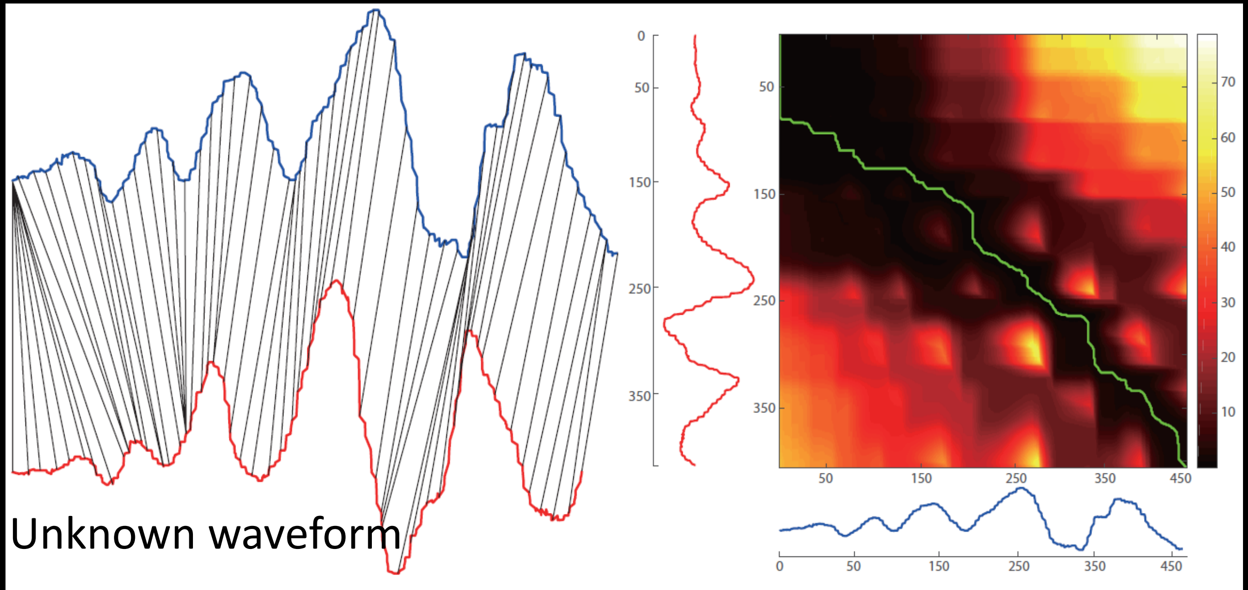
❖ Phase waveform



(a) Two walking activities
(b) Two raise-hand activities

Misalignment
Elastic
Property

Dynamic Time Warping (DTW)



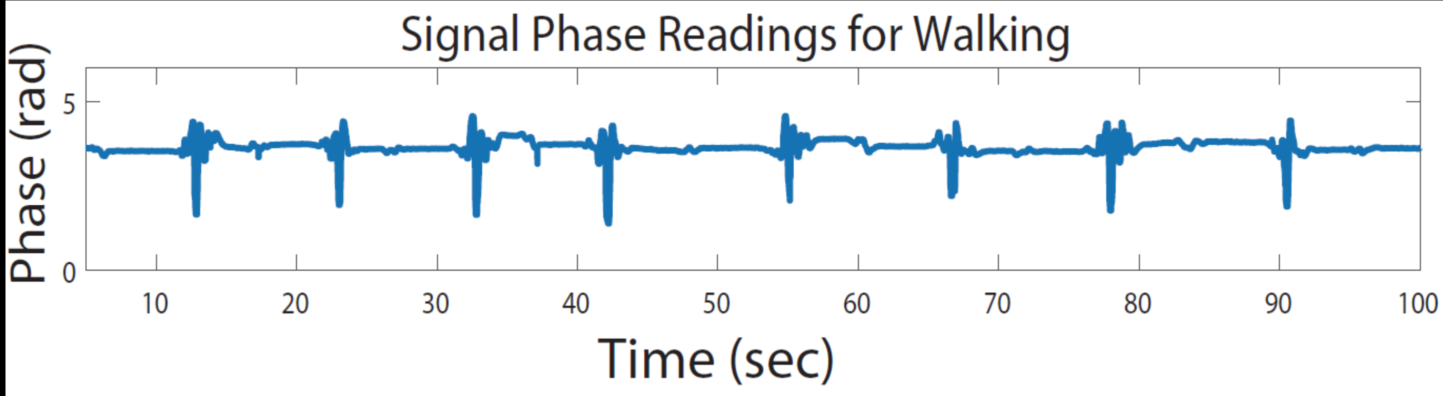
(a) The warping results for two phase waveforms of the same activity.
(b) DTW cost matrix.

Different activities have different phase waveforms, while same activities share similar phase waveforms

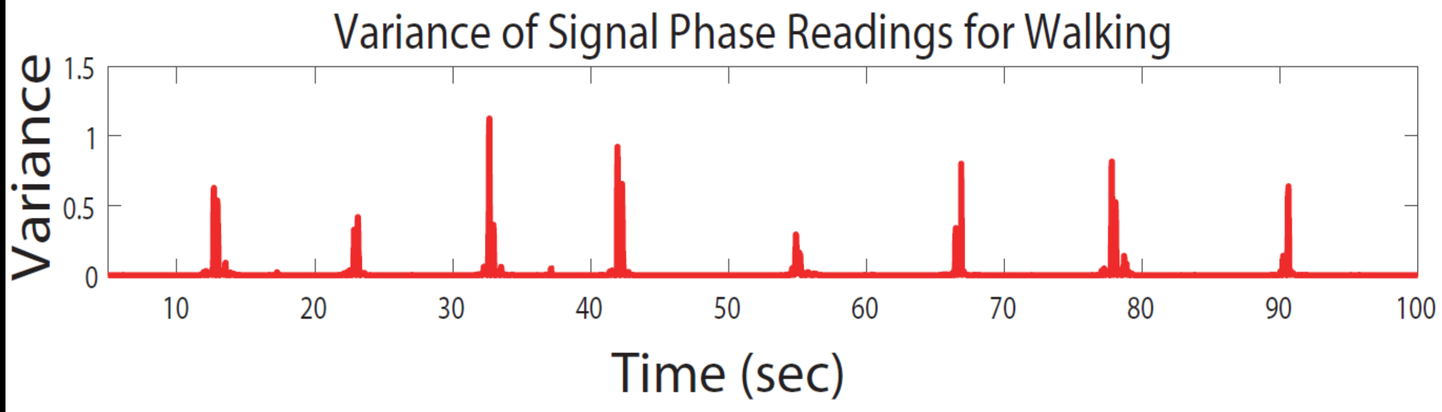
02 Methodology

❖ Time Duration

Objective: To segment the data corresponding to human activities



(a) Phase readings



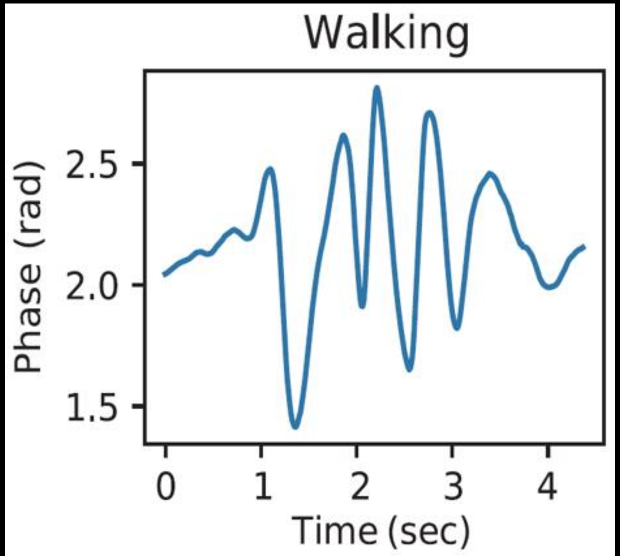
(b) Variance

The **variance** of phase readings can serve as a good indicator for activity segmentation.

02 Methodology

❖ Moving speed

Objective: To measure the moving speed of different activities.

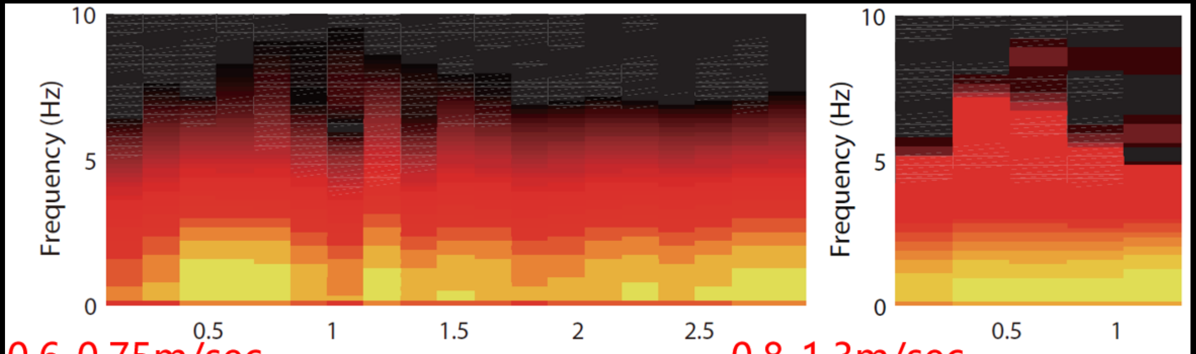


A faster movement results in more rapid fluctuation of phase waveform --- the frequency of phase waveform. $v = f \times \lambda$

Method: Short-Time Fourier Transform (STFT)

- Instantaneously frequency

Spectrogram of walking and falling



(a) The signal phase and moving distance of human walking for 2 meters.

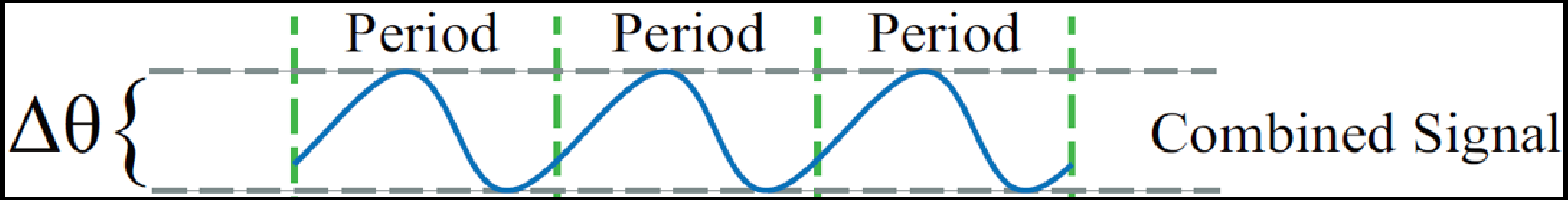
(b) The signal phase and moving distance of human falling down.

walking falling

02 **Methodology**

❖ Moving distance

Objective: To measure the moving distance of different activities.



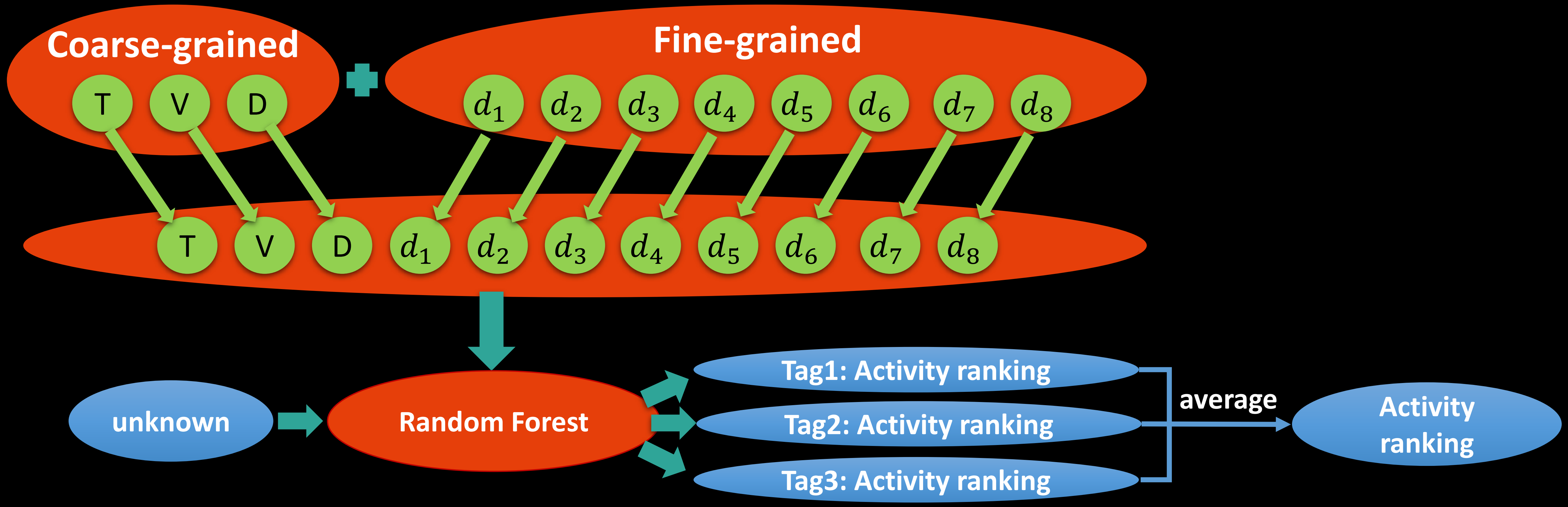
Extract distance from phase difference of 2 consecutive phases.

$$D = \sum_{i=1}^{N-1} \frac{\lambda}{2\pi} \times (|\theta_{i+1} - \theta_i|) \longrightarrow D = \sum_{i=1}^{N-1} \frac{\lambda}{2\Delta\theta} \times (|\theta_{i+1} - \theta_i|)$$

❖ Classification

Coarse-grained features: duration of activity, speed, distance

Fine-grained features: phase waveform



Extracted Features

System Performance

Robustness

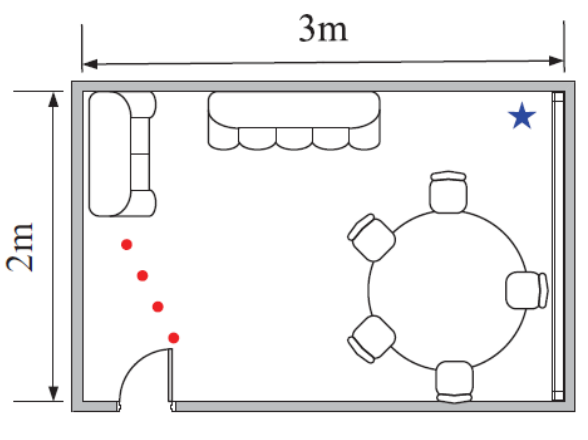
03 Evaluation

Experiment settings

(a) Reader, tags, and antenna.

COTS RFID System

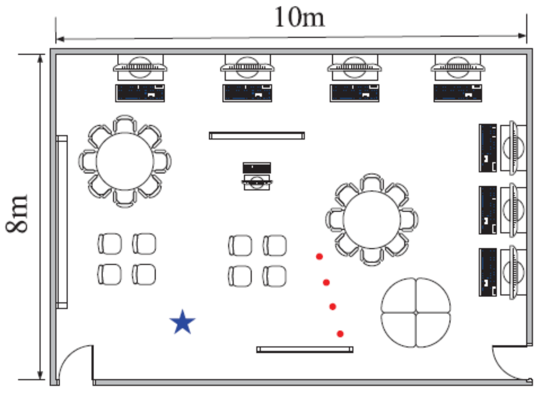
- Impinj R420 Reader
- Commodity passive tags
- Directional Antenna



(b) Layout of roomA.

Room A

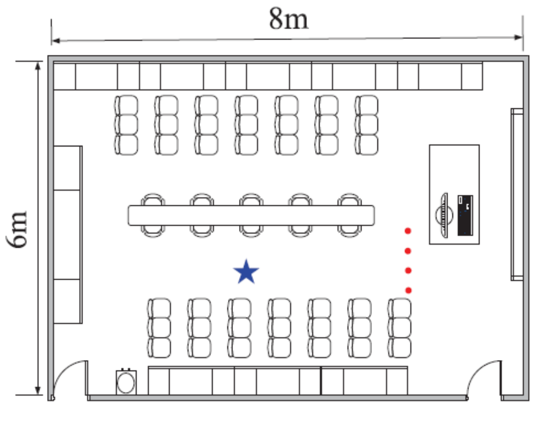
- Small size with 3m*2m



(d) Layout of roomC.

Room C

- Large size with 10m*8m



(c) Layout of roomB.

Room B

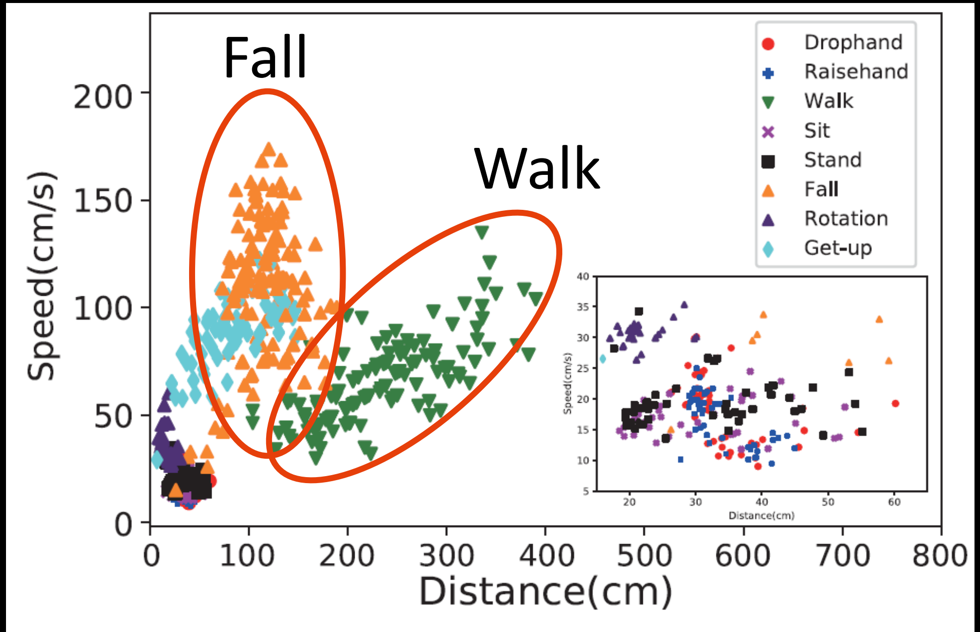
- Median size with 8m*6m

X 12

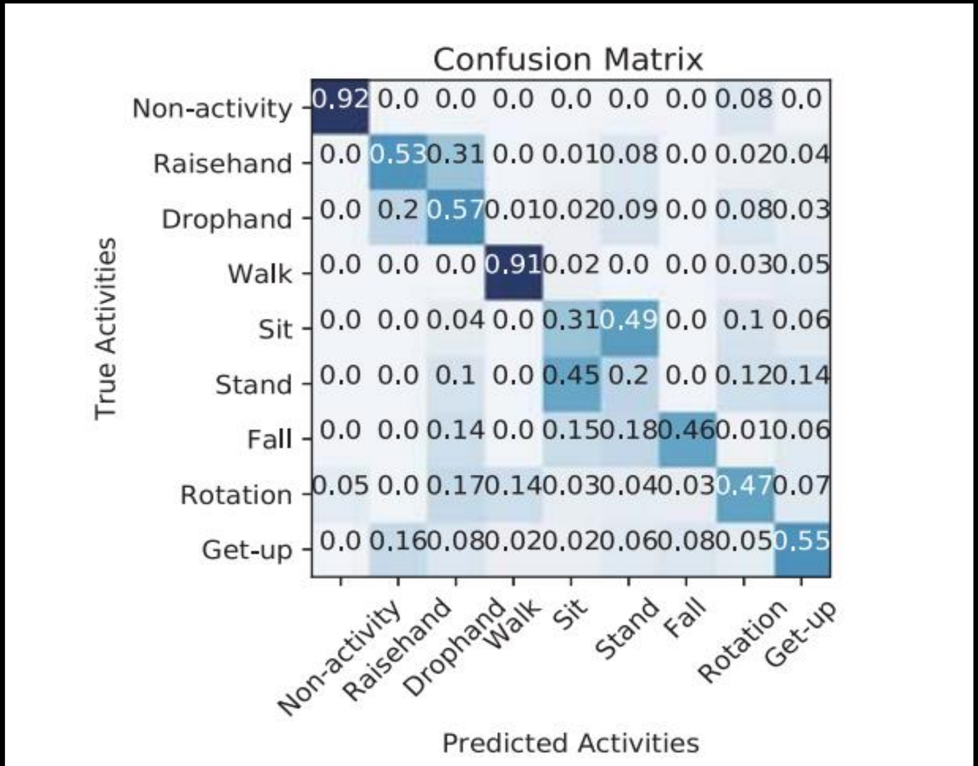
640 traces for training
1280 traces for evaluation
10-fold cross-validation

03 **Evaluation**

Extracted Features



(c) The speed-distance feature mapping of all eight activities.



Coarse-grained features

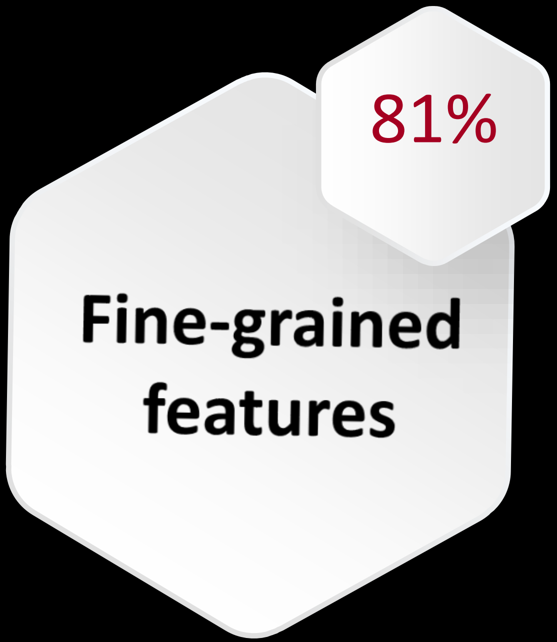
58%

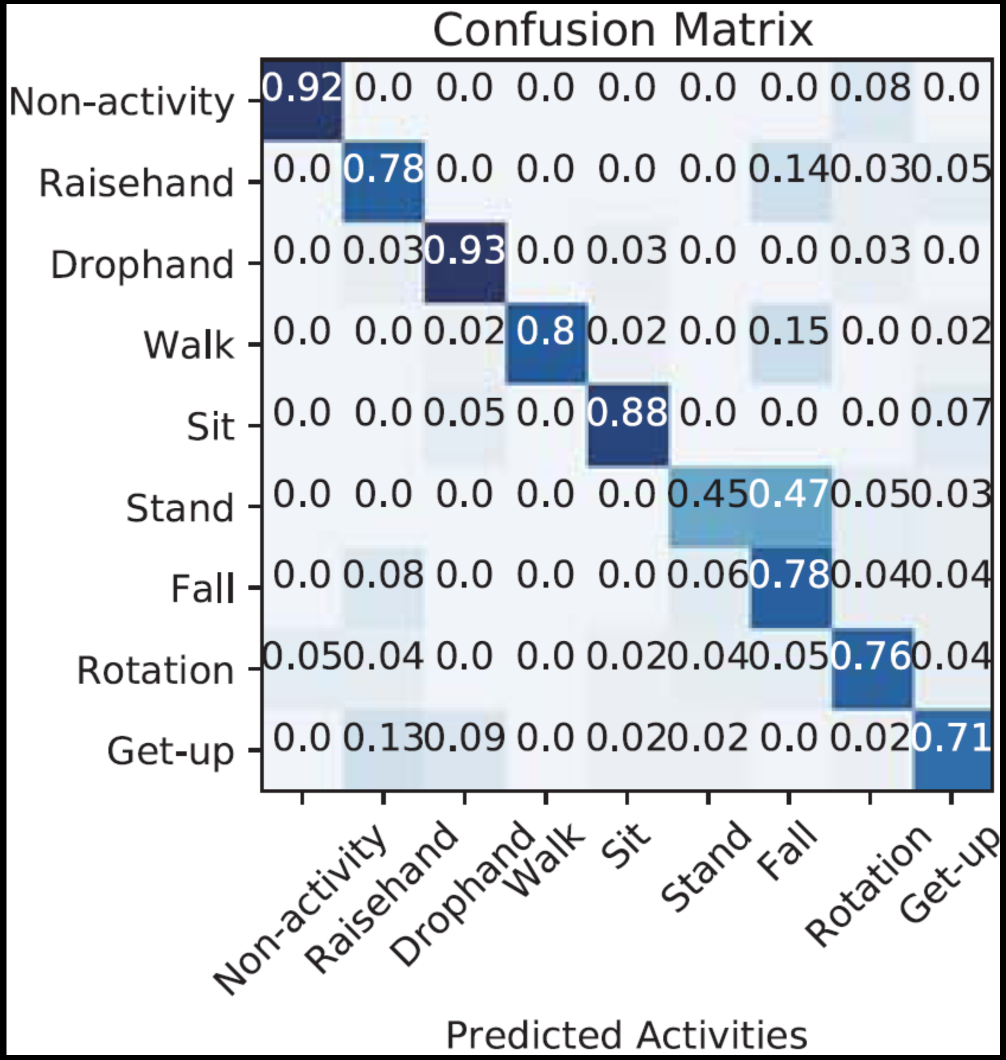
- The speeds of falling and walking significantly differ with other activities
- Walking has longer moving distances
- Other activities are difficult to distinguish
- Only using coarse-grained feature may not work

System Performance

Fine-grained features

8 DTW distances





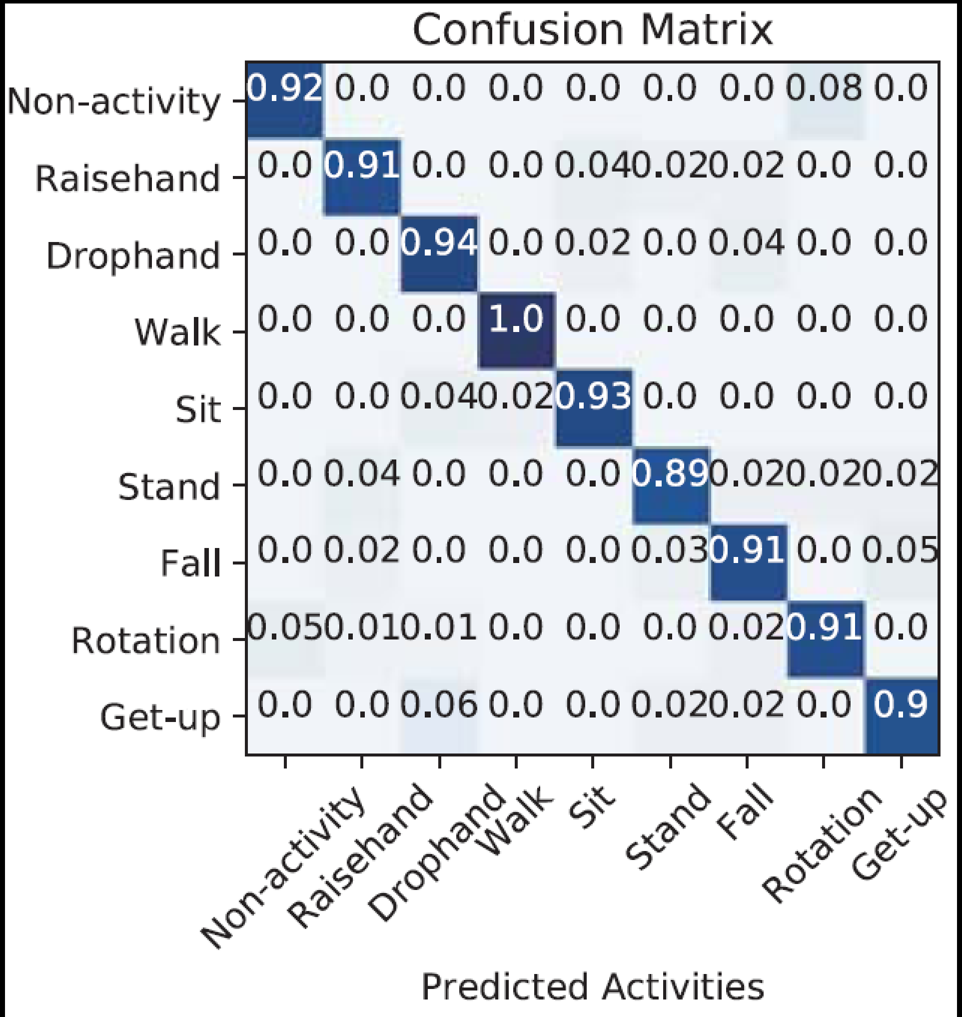
03 Evaluation

System Performance

Fine-grained + Coarse-grained features

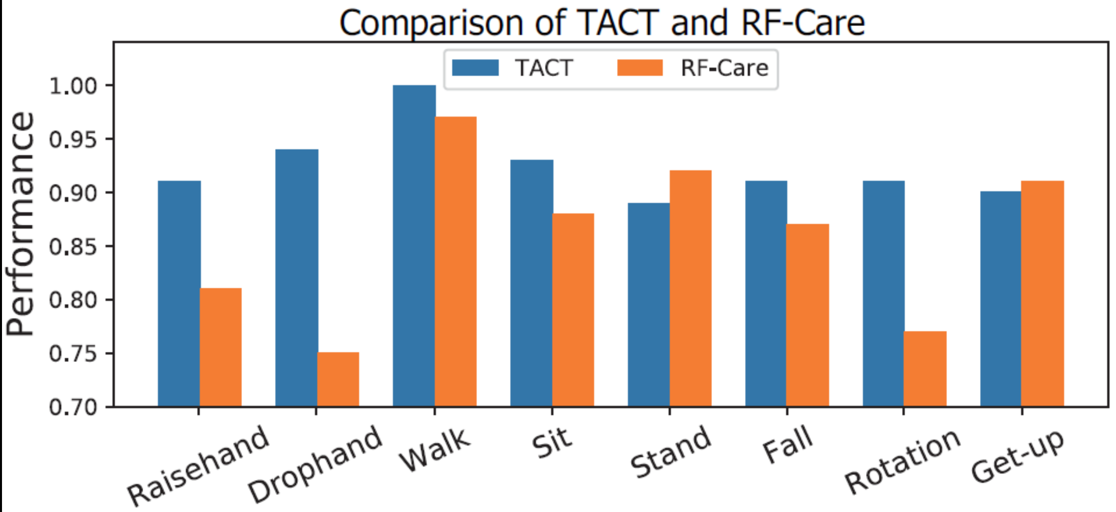
Combined features

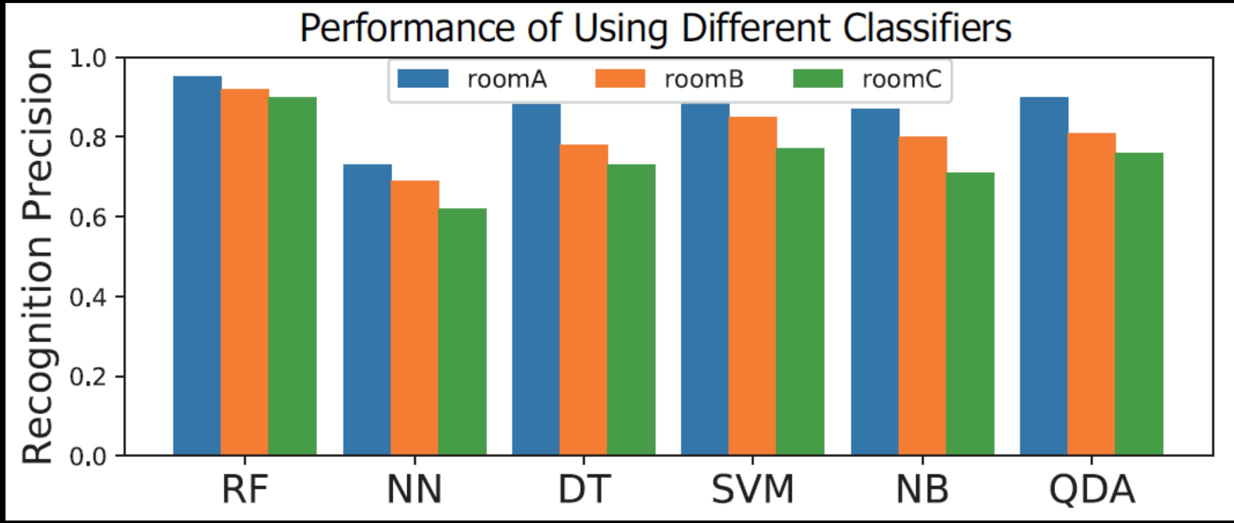
93%



03 Evaluation

System Performance





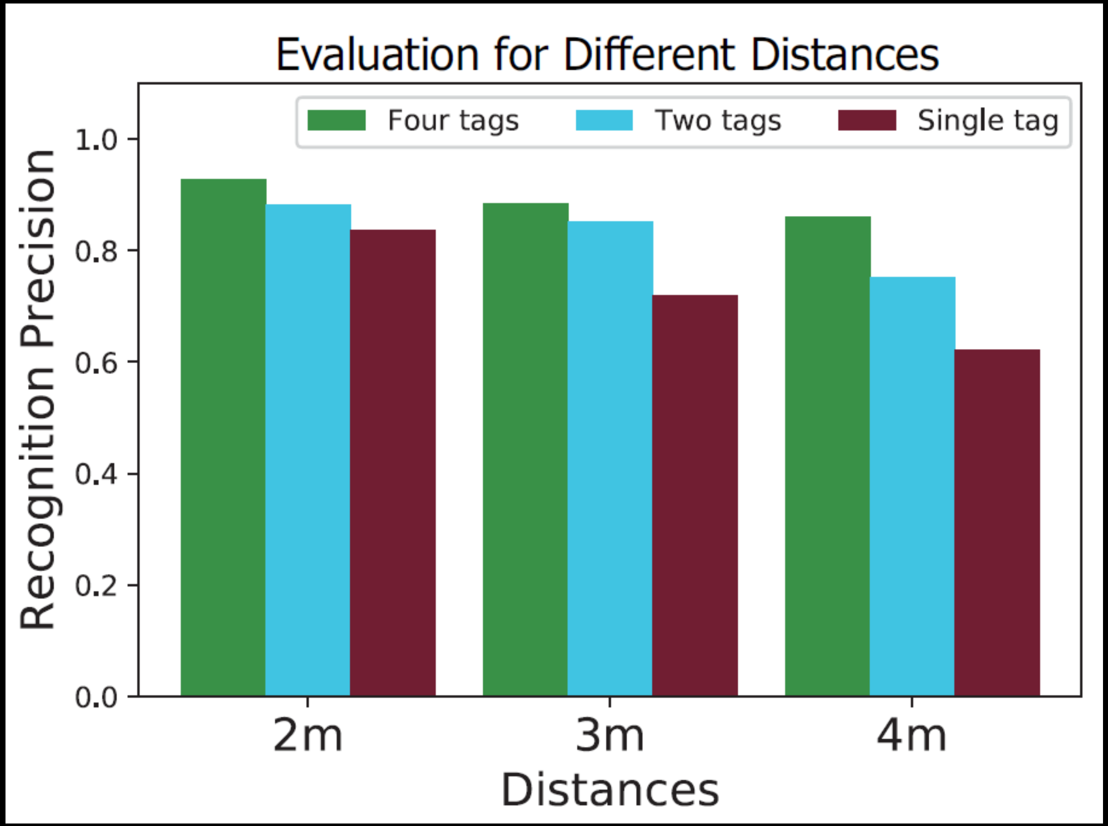
Compare to existing work

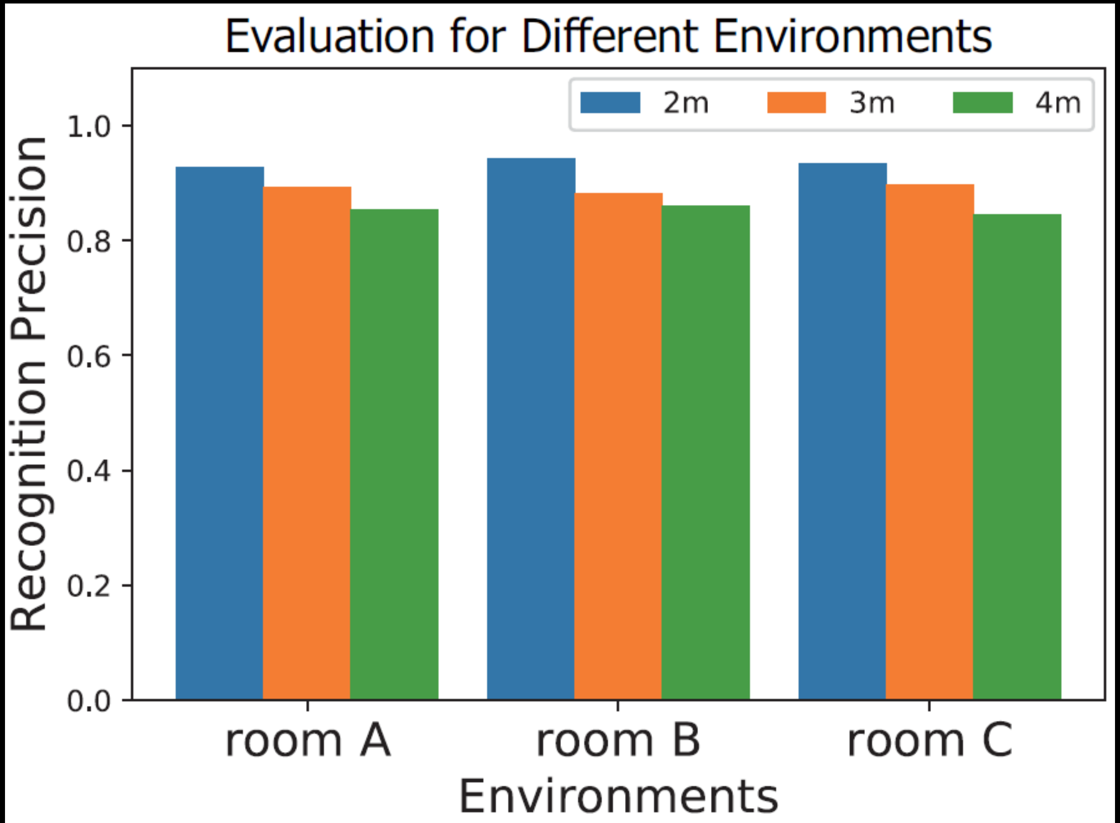
Six classifiers

Our TACT system significantly outperforms RF-Care

RF-Care: Lina Yao, Quan Z. Sheng, Wenjie Ruan, Tao Gu, Xue Li, Nick Falkner, and Zhi Yang. 2015. RF-Care: Device-Free Posture Recognition for Elderly People Using A Passive RFID Tag Array. In proceedings of the 12th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (MOBIQUITOUS'15).

Robustness





Deploying multiple tags indeed can improve the system performance

Environment has relatively small impact on the performance

Conclusion

04 Conclusion

- Build a contact-free model which can be used to quantify the correlation between signal phase values and key features of human activities.
- Coarse-grained & Fine-grained features combination
- Implementation of the contact-free activity recognition system using RFID technology
- Extensive evaluation under different settings， and the average recognition precision -- up to 93.5%.

Thanks!

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UbiComp 2019, London
September 11th, 2019

02 Methodology

Pre-process	Extraction	Classification	Identification
Data	**Features**	**Classifier**	**Activities**
Remove Frequency Hopping	Coarse-grained Fine-grained Features	Random Forest, Neural Network, Decision Tree, SVM, Naïve Bayesian, QDA	Walking, Falling, Sitting, Standing, Raisehand, Drophand, Rotation, Get-up