ShakeReader: 'Read' UHF RFID using Smartphone

Kaiyan Cui[1,2], Yanwen Wang[3], Yuanqing Zheng[1], Jinsong Han[4]

[1]The Hong Kong Polytechnic University, Hong Kong, China

[2]Xi'an Jiaotong University, Xi'an, Shaanxi, China

[3]Hunan University, Changsha, Hunan, China

[4]Zhejiang University, Hangzhou, Zhejiang, China

Background: RFID for Retailers

Importance for retailers

- ✓ Asset Tracking
- ✓ Supply Chain Management
- ✓ Automated Inventory
- ✓ …

Retailers can benefit tremendously from RFIDs.

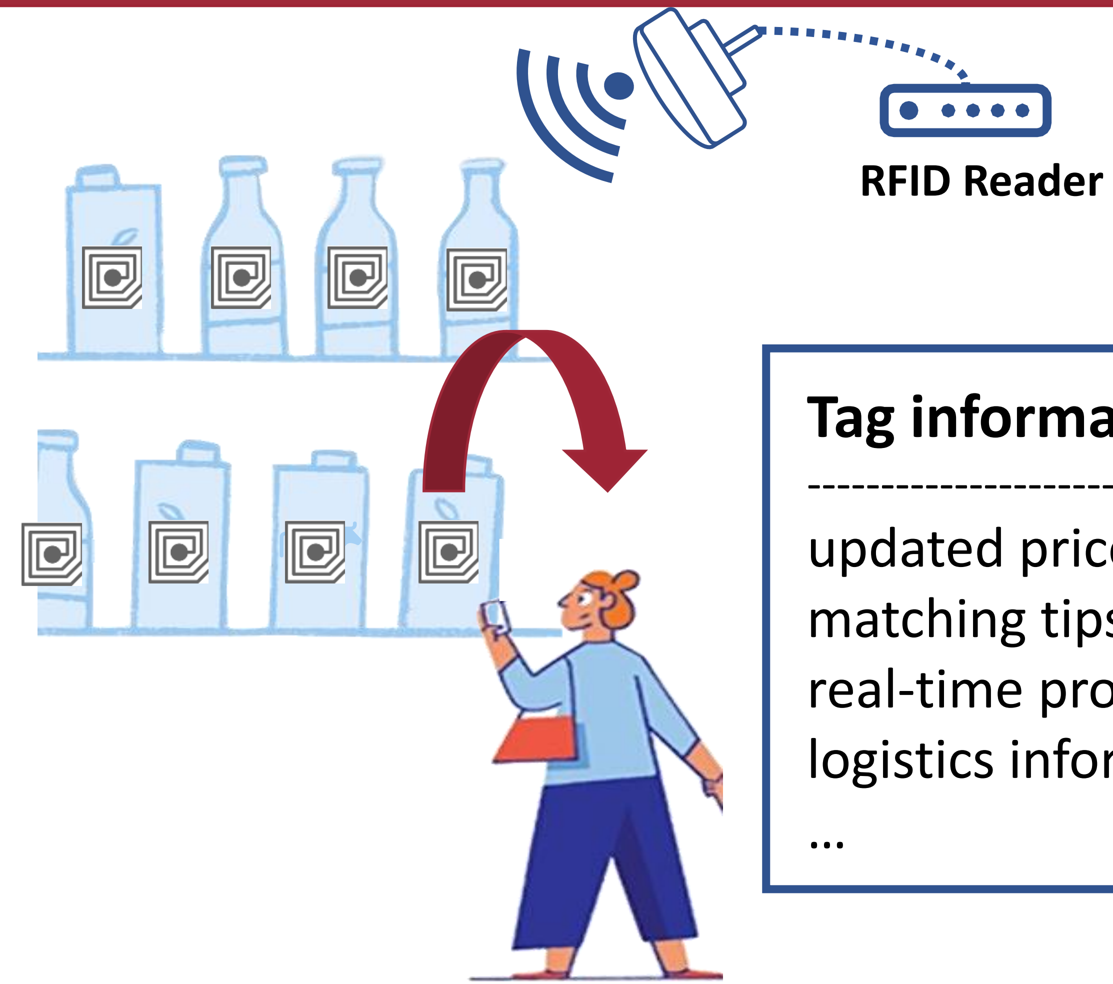
Background: RFID for Customer

- Where is RFID?
- What does RFID do for me?

- GSM/LTE B20 overlap
- Power consumption

Customers cannot benefit from deployed RFID infrastructure because that UHF RFIDs are not supported by current smart devices !

Our Goal



Tag information:

----

updated price,
matching tips,
real-time promotion,
logistics information,
…

New applications

- For customers:
  - Item-specific information
  - Product safety
  - Product traceability
  - …
- For retailers:
  - Customer shopping behaviour
  - ….

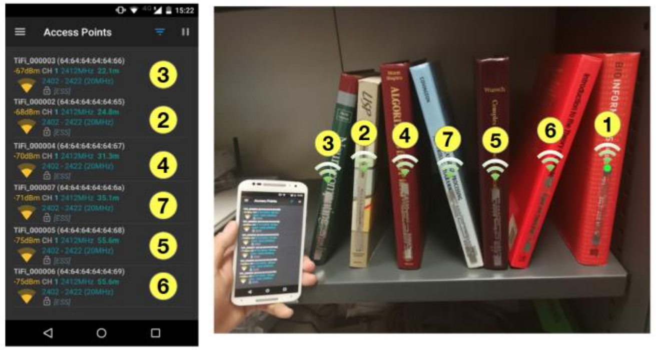
We aim to enable customers to 'read' RFID tags by bridging the gap between the deployed RFID infrastructure and smartphones

Existing Solutions

❖Handheld readers


- Expensive
- Extra hardware
- High power consumption
- Do not support one-to-one interaction

❖Cross-technology communication[1]

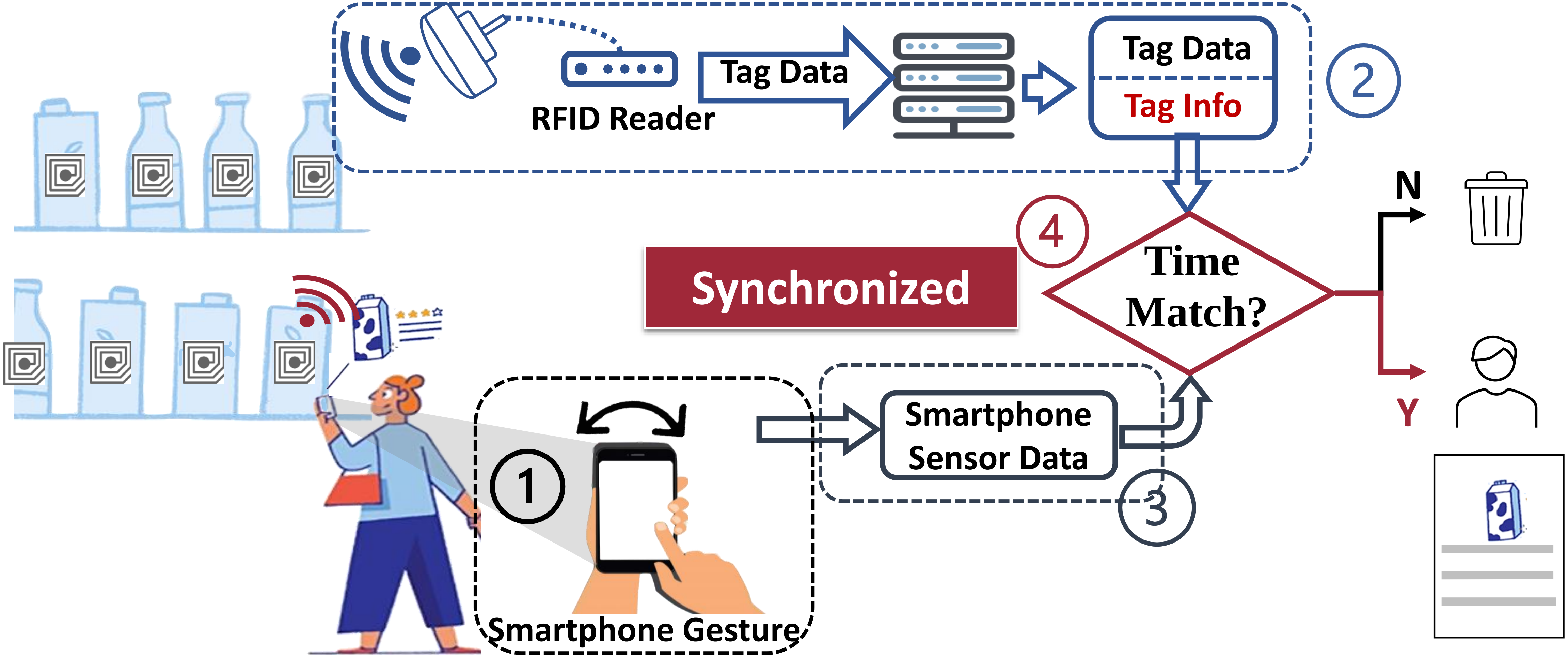


- Do not support one-to-one interaction

Customers will receive so many tag information for one scan and it is difficult to find the desired one.

[1] Z. An, L. Yang, and Q. Lin. Cross-Frequency Communication: Near-Field Identification of UHF RFIDs with WiFi! in Proc of ACM MobiCom, 2018.

Our Idea: ShakeReader



We leverage the synchronicity of RFID data and sensor data caused by the same smartphone gesture to 'read' the interested RFID tag .

Challenge

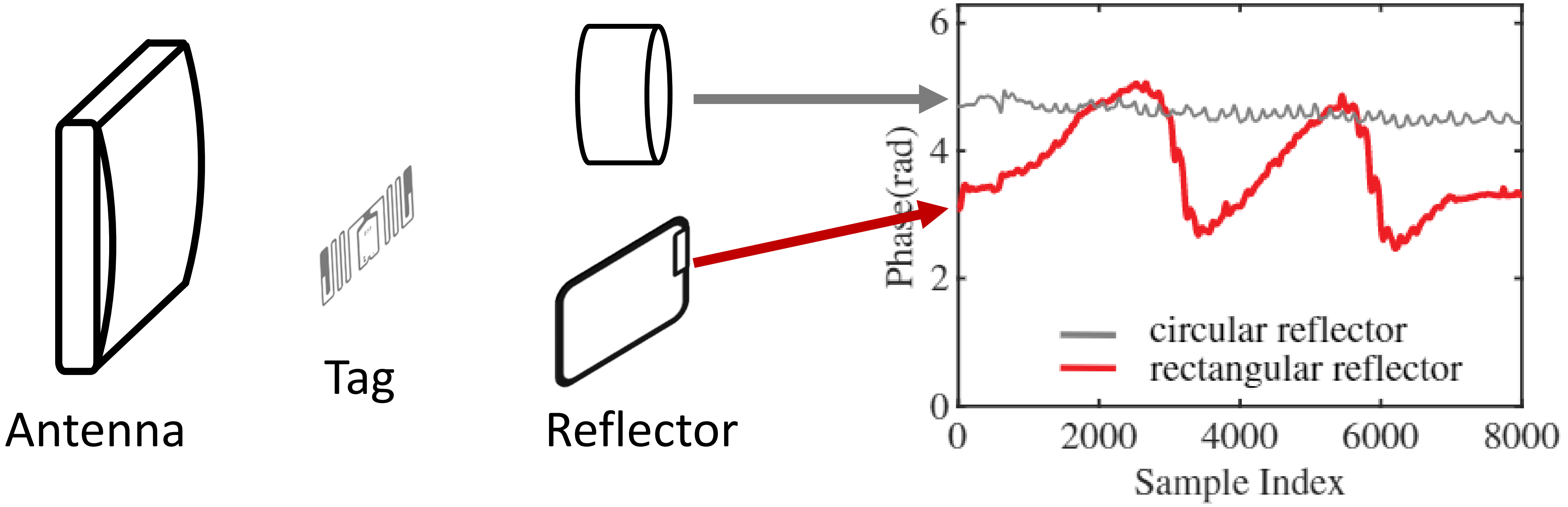
In our scenario:

- Only one RFID tag
- The tag is attached to an item
- Both the item and the RFID reader are fixed

How to design a smartphone gesture, which can be detected by one static tag?

Solution: Reflector Polarization

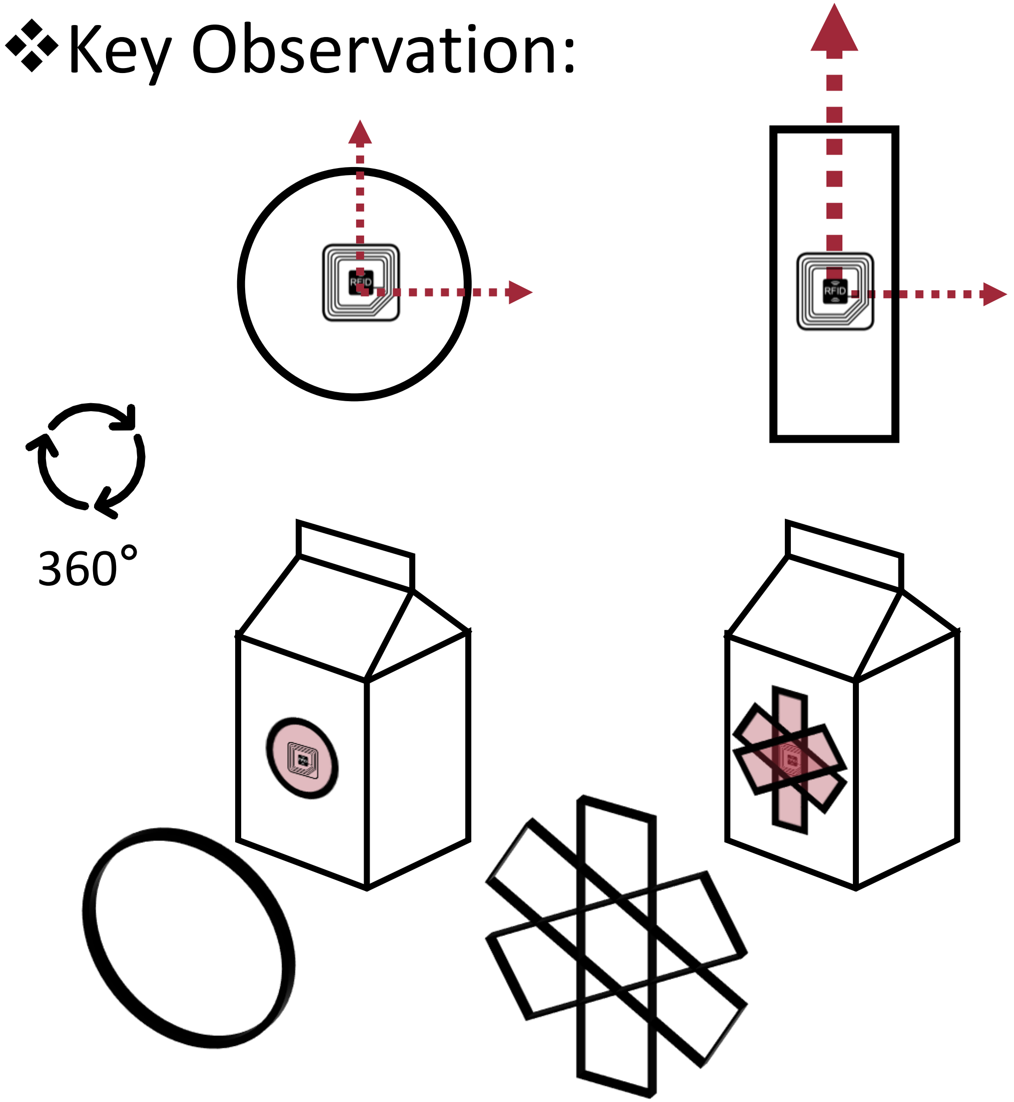
❖Key Observation:



The rotation of the rectangular reflector will affect the received signal，even though both tag and antenna remain static.

Solution: Reflector Polarization

❖Key Observation:

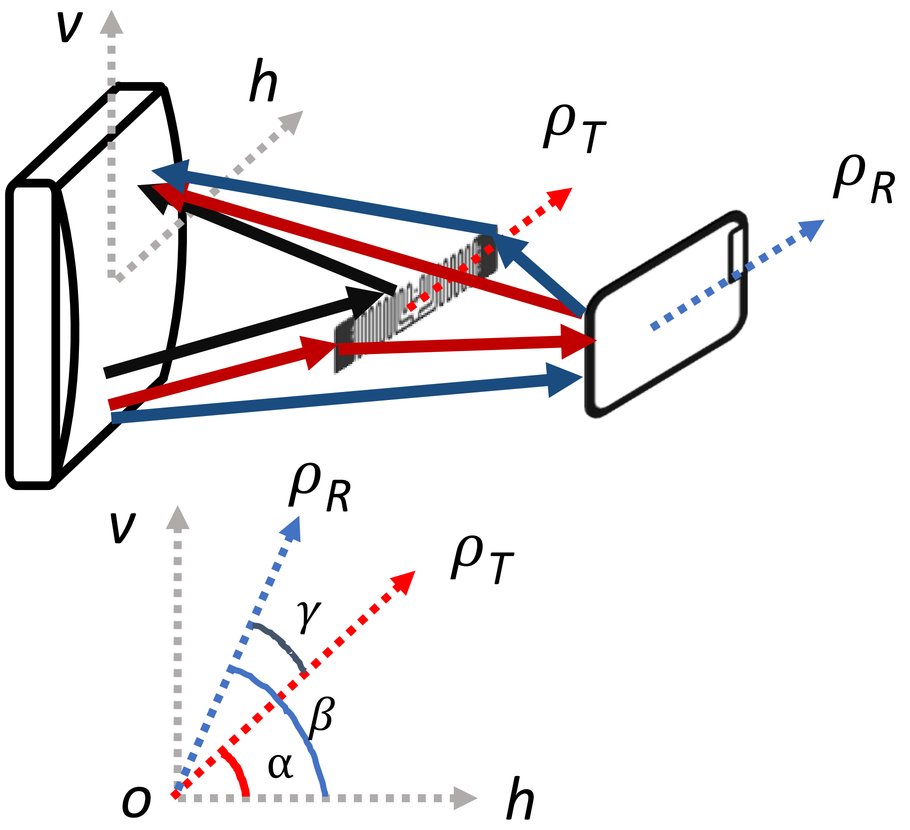


- differences in length and width of the reflectors
- the signal reflected along the long axis dominates the reflected signal strength

The rotating polarization of rectangular reflector will affect the tag's phase values, even though both tag and antenna remain static.

Solution: Reflector Polarization

❖Reflector Polarization Model:

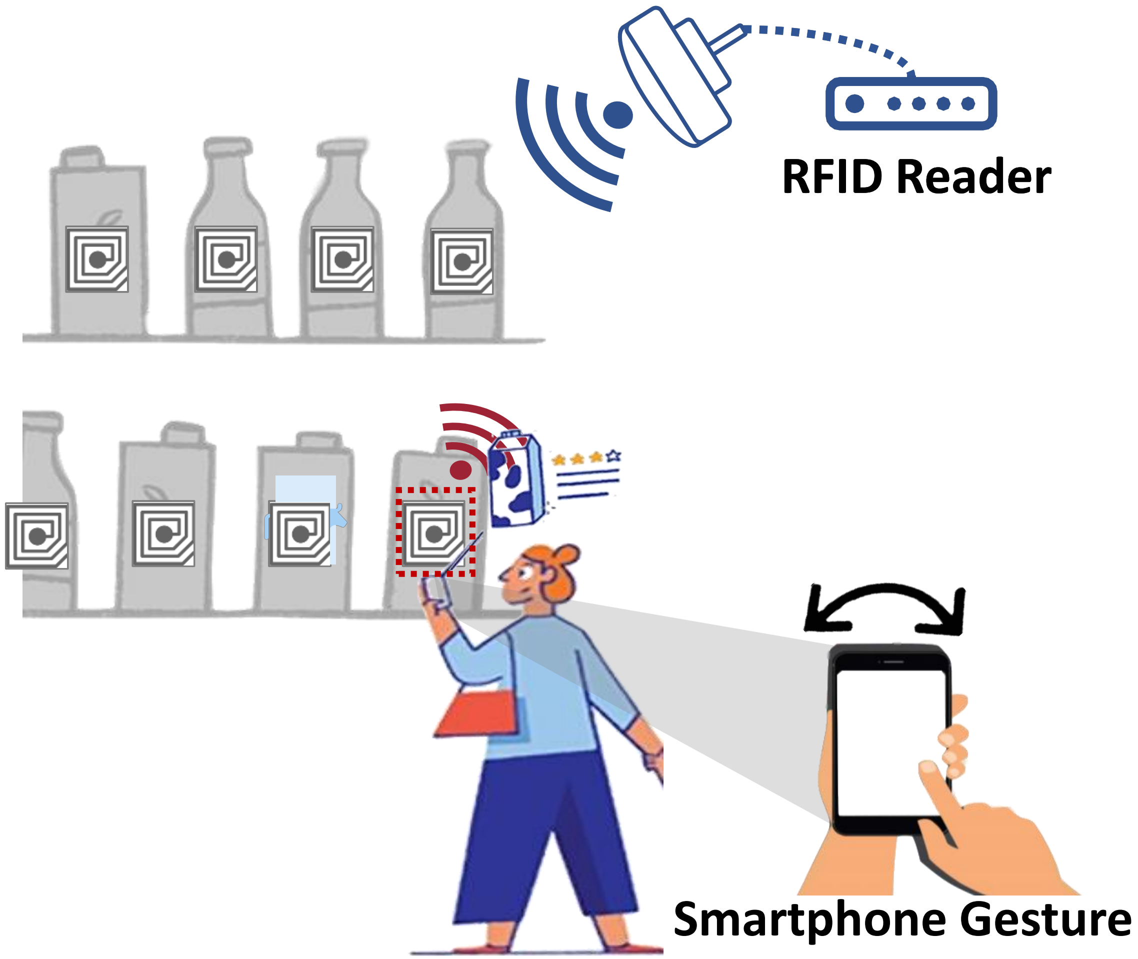


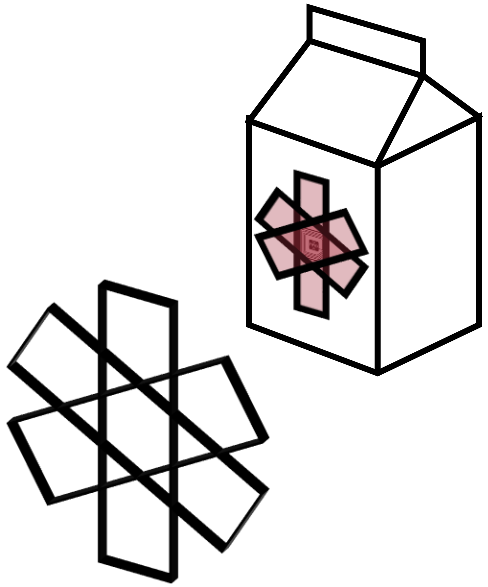
- Received Signal R(t)
  1. Antenna-Tag- Antenna
  2. Antenna-Tag-Reflector-Antenna
  3. Antenna-Reflector-Tag-Antenna

$$R(t)=S_{A\to T\to A}(t)+S_{A\to T\to R\to A}(t)+S_{A\to R\to T\to A}(t)$$
$$= f(\alpha, \beta, \gamma, d_{A\to T\to R\to A})$$

The propagation distances and the polarization directions of tag, reflector, and antenna jointly affect the received backscattered signal.

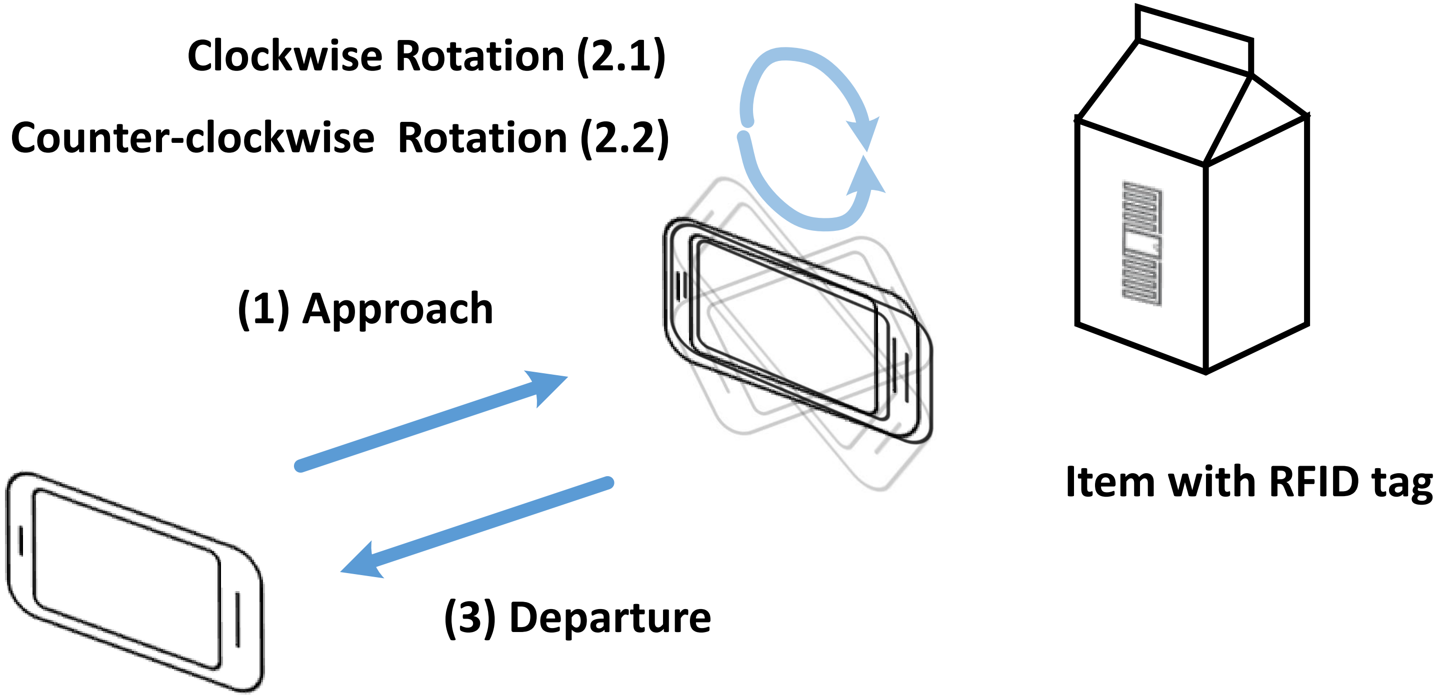
Solution: Reflector Polarization





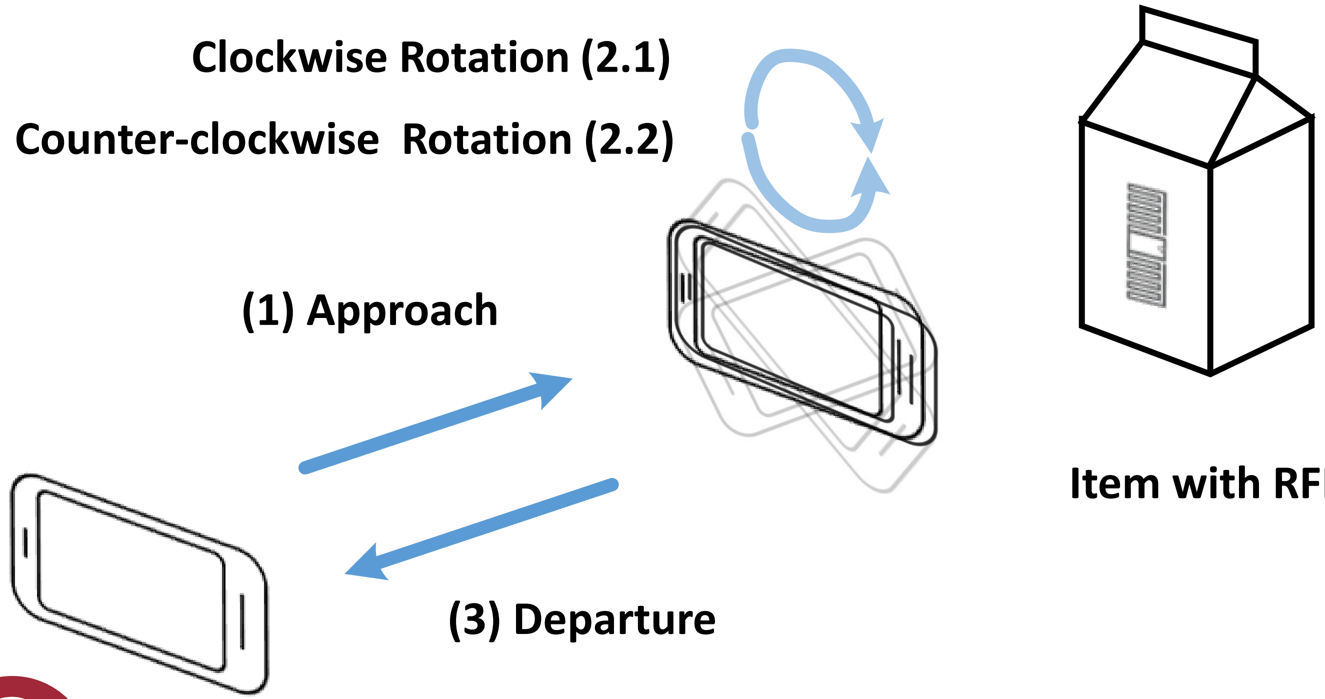
We leverage the smartphone rotation as the interactive gesture to specify user's interest in a static tag.

Smartphone Gesture



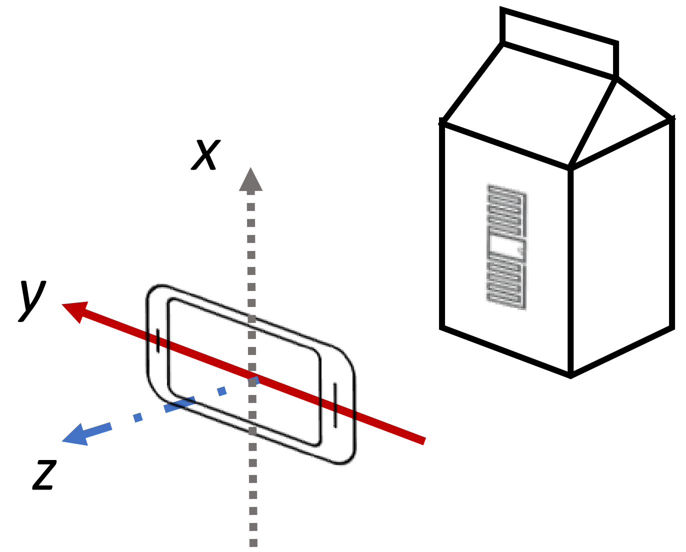
We design a combined gesture to prevent the influence of other human activities

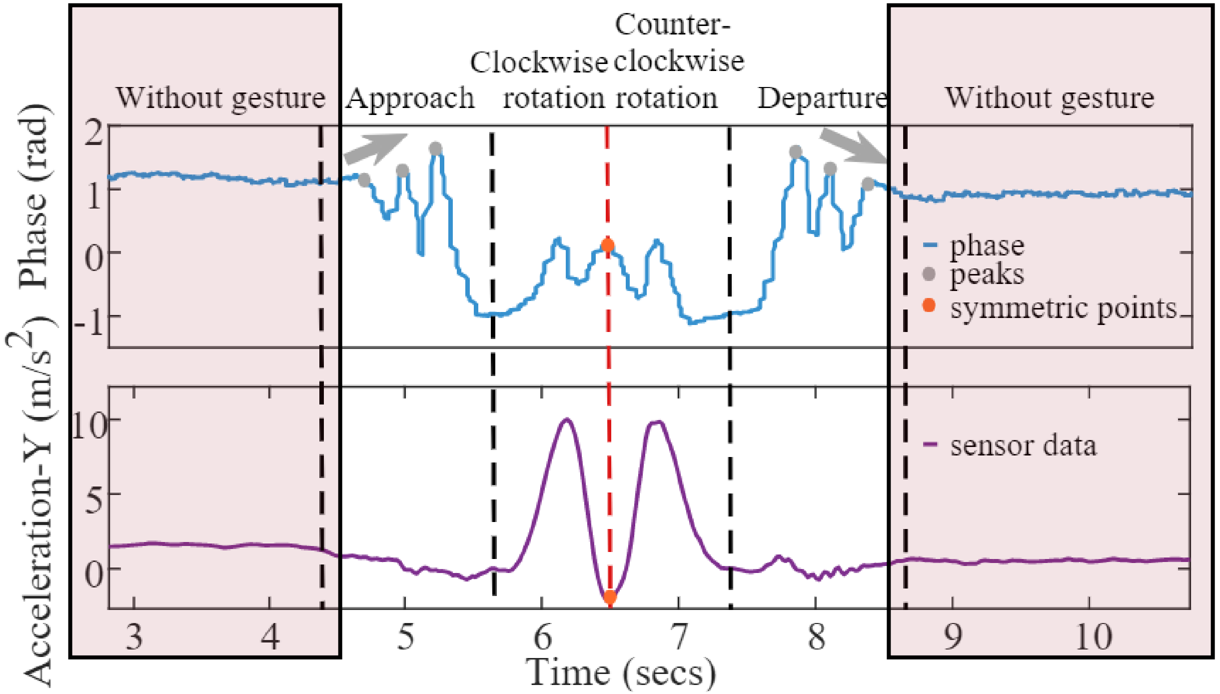
Smartphone Gesture



How to **detect** this smartphone gesture?

Smartphone Gesture Detection

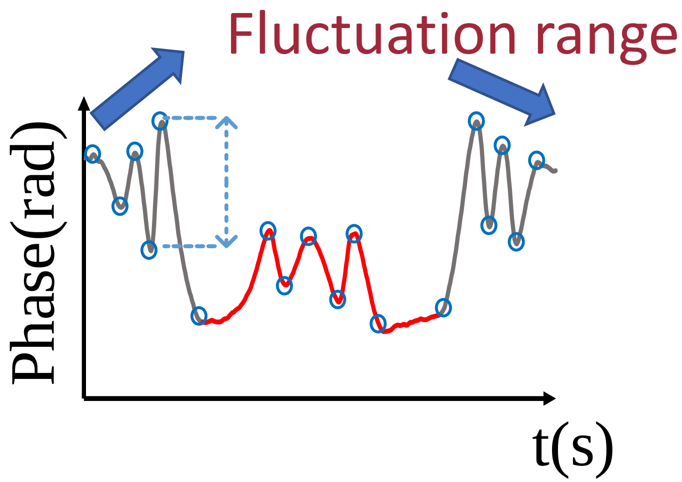




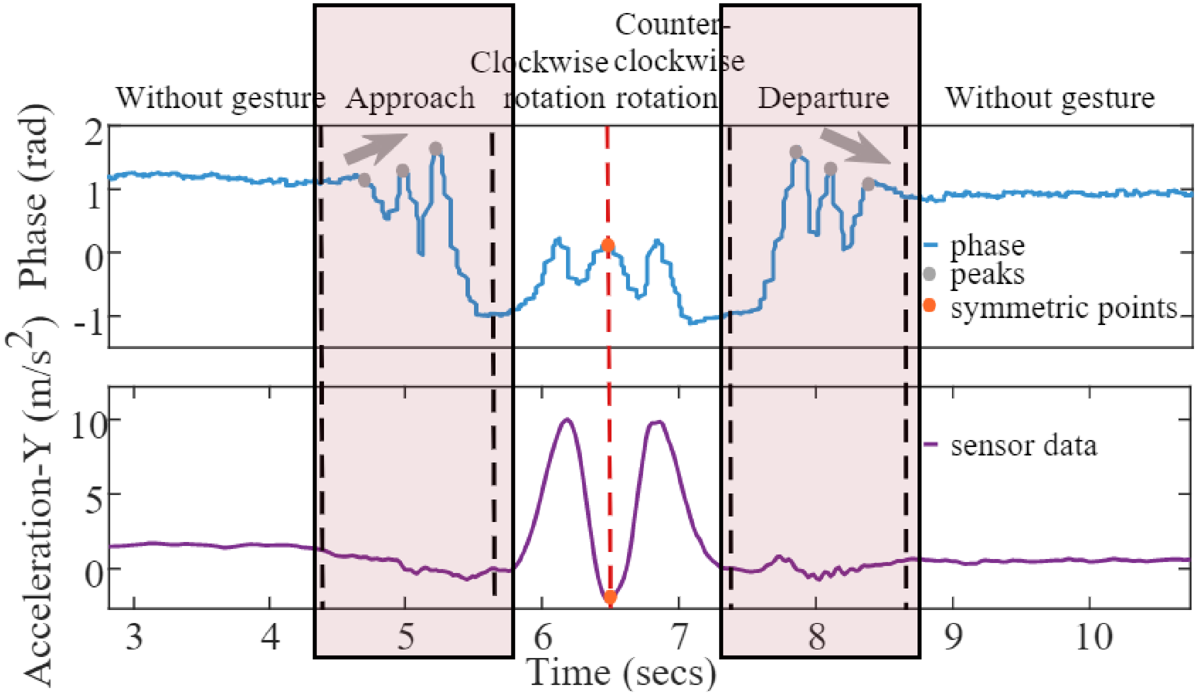
1) Starting Point and Finishing Point Detection: measure the standard deviation of phase and acceleration readings.

2) Approach and Departure Detection: the phase values fluctuate with the distance change between the tag and the phone. Acceleration-Y readings fluctuate slightly.

Smartphone Gesture Detection



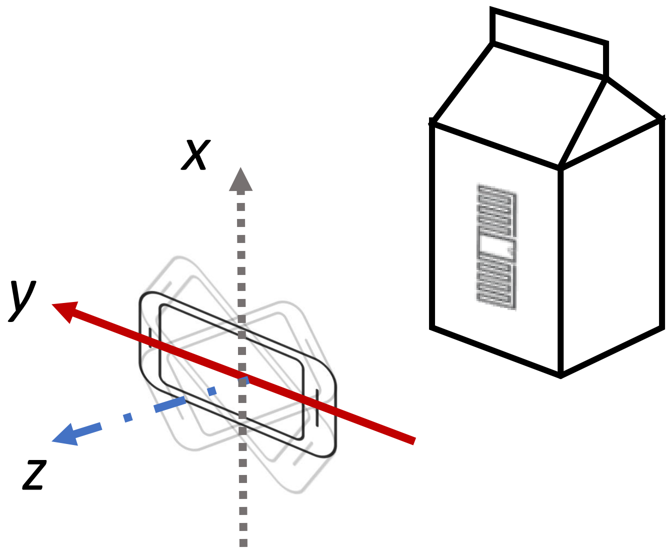
Fluctuation range: the difference between two adjacent local maximum and local minimum.

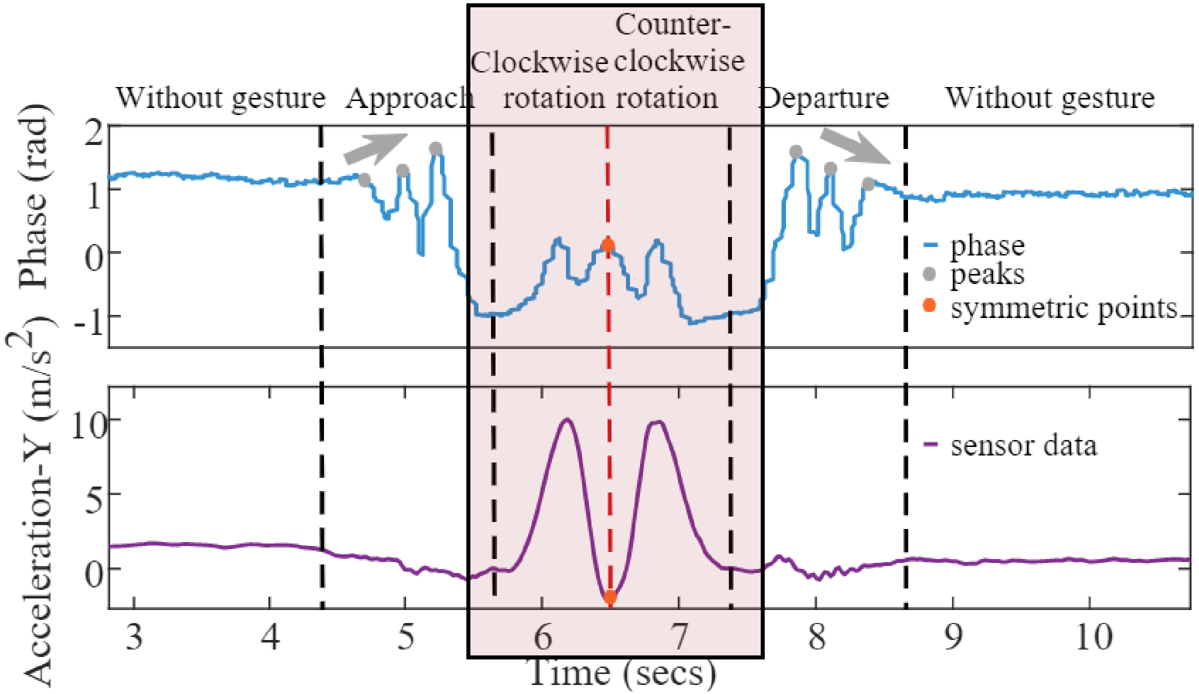


1) Starting Point and Finishing Point Detection: measure the standard deviation of phase and acceleration readings.

2) Approach and Departure Detection on phase readings: find approach pattern and departure pattern based on fluctuation range

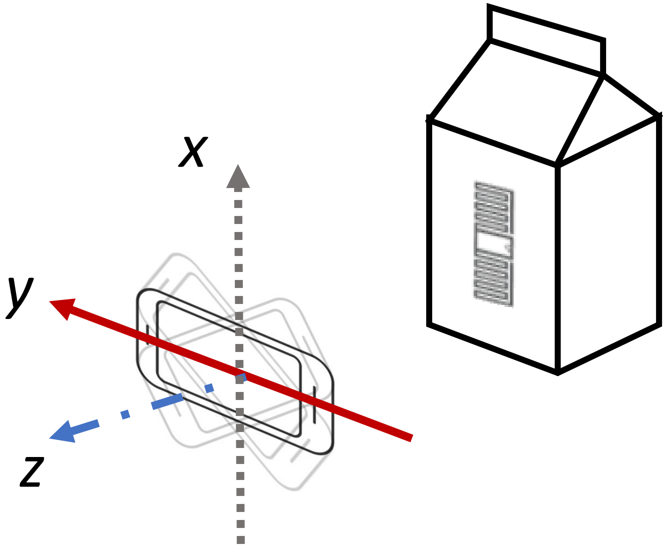
Smartphone Gesture Detection

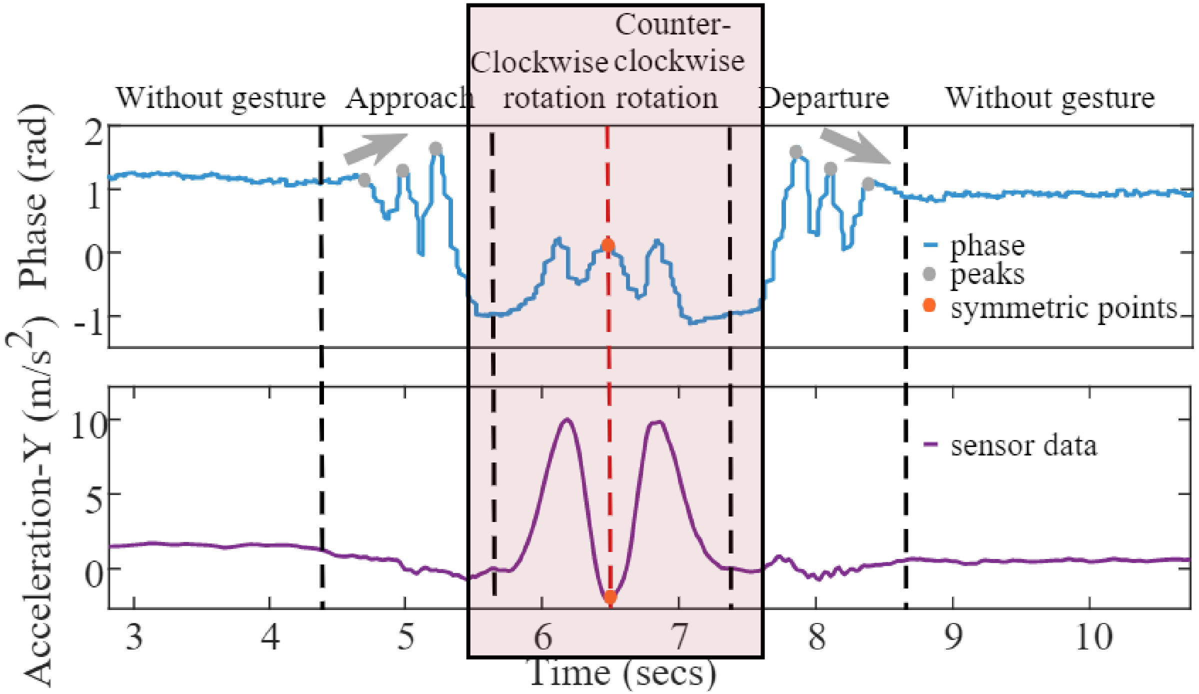




3) Rotation Detection: phase values: 'W' shape. Acceleration-Y readings: 'M' shape. We utilize DTW algorithm to detect this symmetric rotation.

Smartphone Gesture Detection

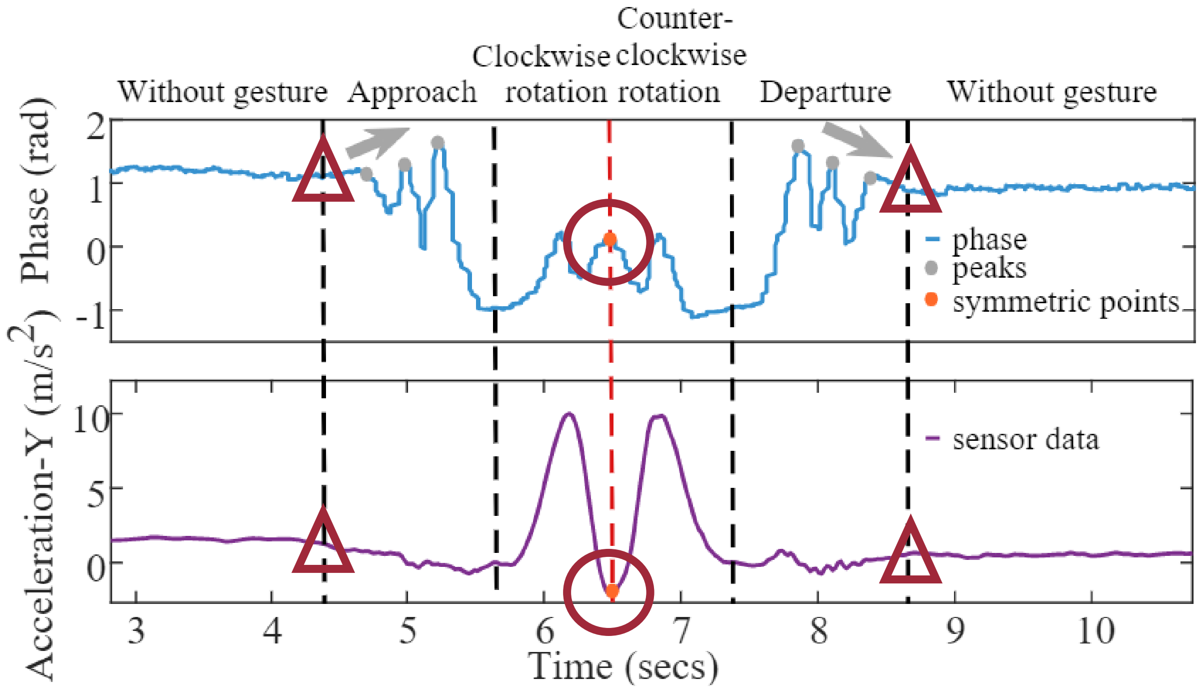




How to match the interested tag with its corresponding smartphone user?

Matching

❖ Synchronicity between RFID data and sensor data



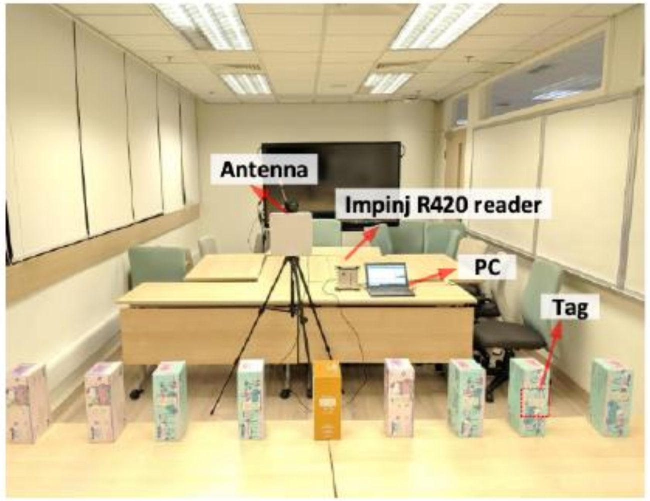
Three key timing information:

- Symmetric point timestamp
- Starting point timestamp
- Finishing point timestamp

We extract the three key timing information to match the interacted tag with its corresponding smartphone user.

Evaluation

- Experimental Scenarios:
  - typical office room
  - a shelf Scenario
- Hardware:
  - Impinj R420 reader
  - Larid antenna A9028
  - three kinds of commercial tags
  - three kinds of smartphones with different materials
- Metrics:
  - Accuracy
  - False Accept Rate (FAR)
  - False Reject Rate (FRR)

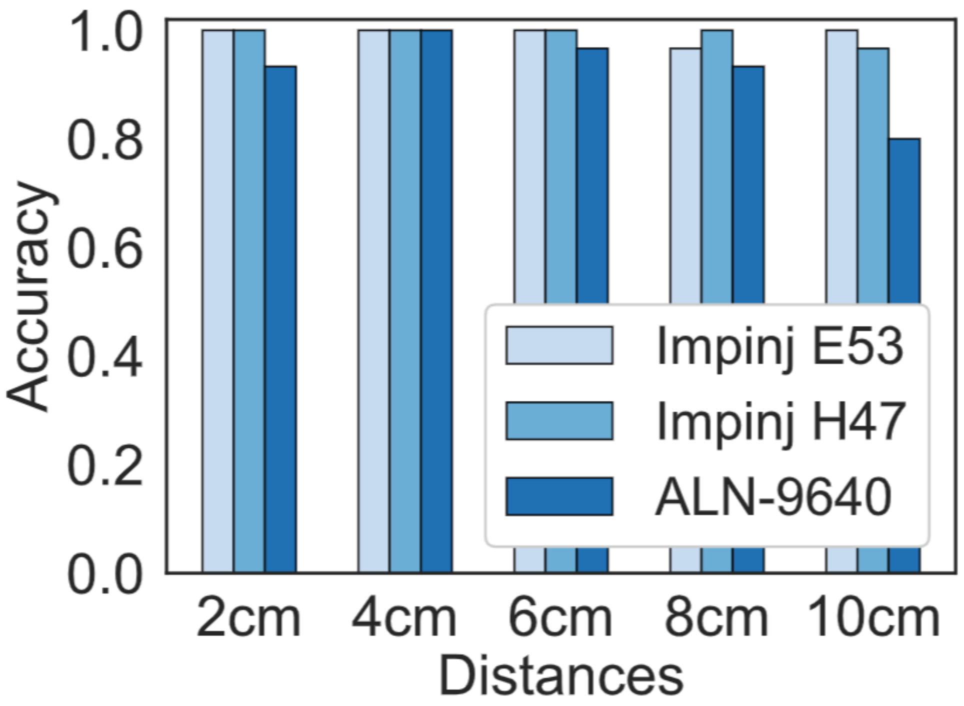


Evaluation

- RFID based Smartphone Gesture Detection
  - Impact of smartphone-to-tag distance
  - Impact of smartphone materials
  - Impact of tag-to-tag distance
  - …

- Overall performance
  - System accuracy
  - System latency

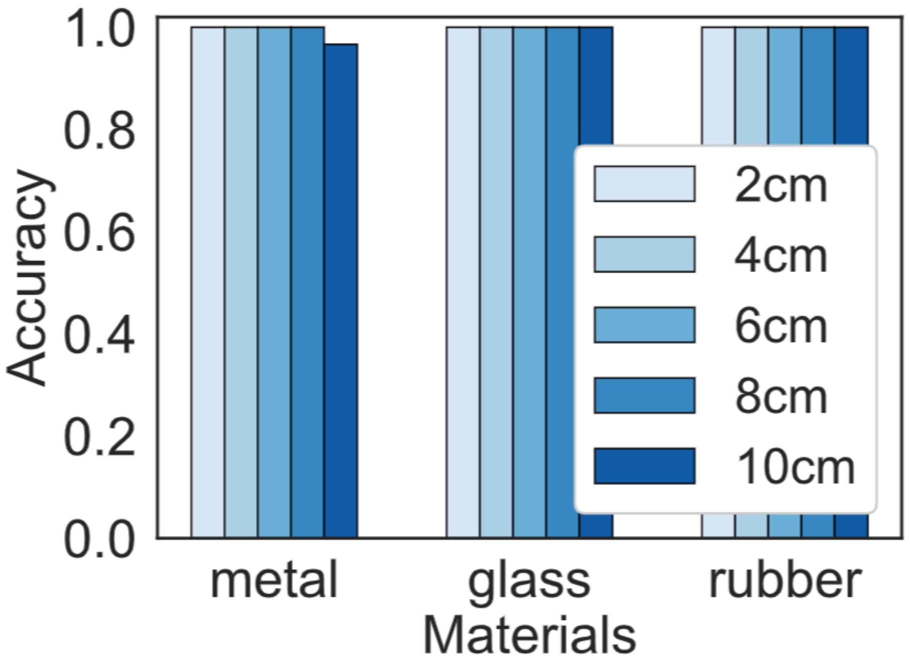
Impact of smartphone-to-tag distance



Detection accuracy of three kinds of tags with different smartphone-to-tag distances

- Average accuracy: over 95%
- A user needs to make smartphone gesture within 10 cm

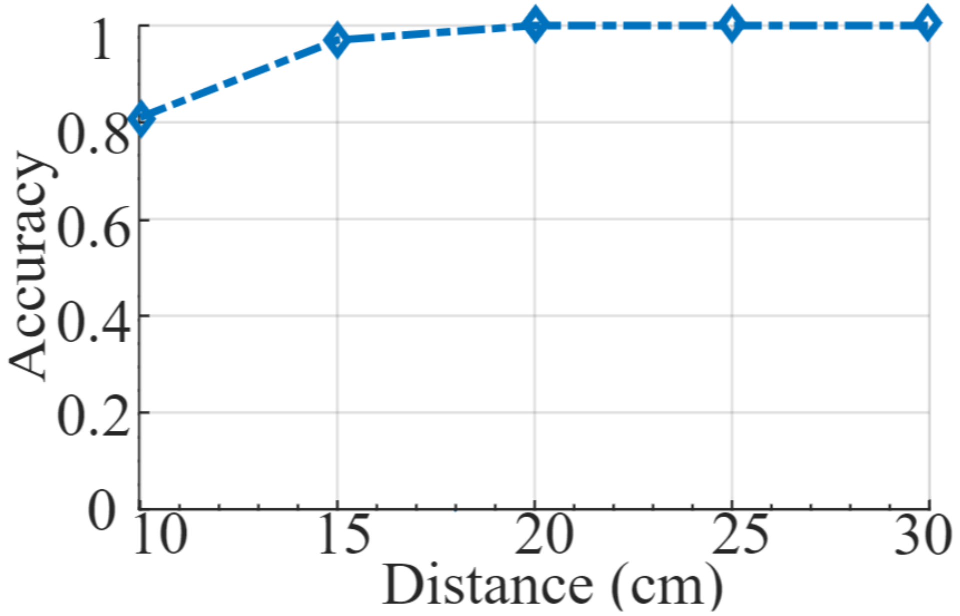
Impact of smartphone materials



Detection accuracy of different smartphone materials

- Almost all the gestures performed using smartphones with different back cover materials can be detected.

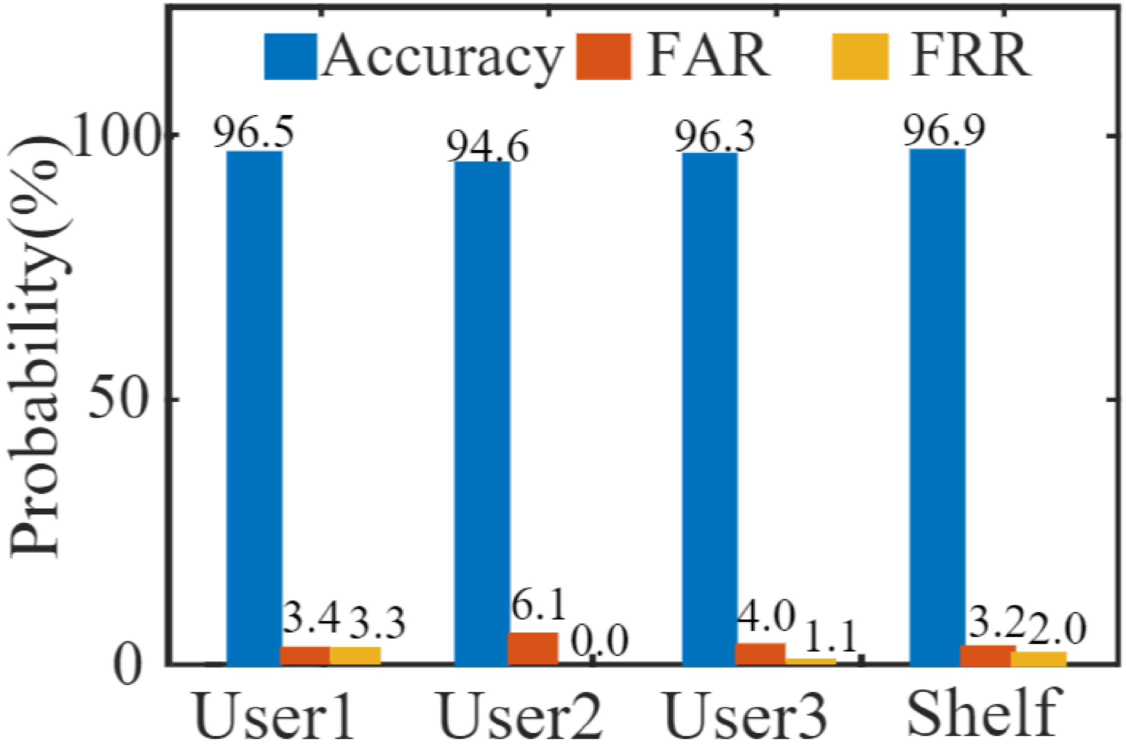
Impact of tag-to-tag distance



Detection accuracy with different tag-to-tag distances

- Larger tag-to-tag distance → higher accuracy
- When the tag-to-tag distance exceeds 15cm, our system can detect almost all gestures.

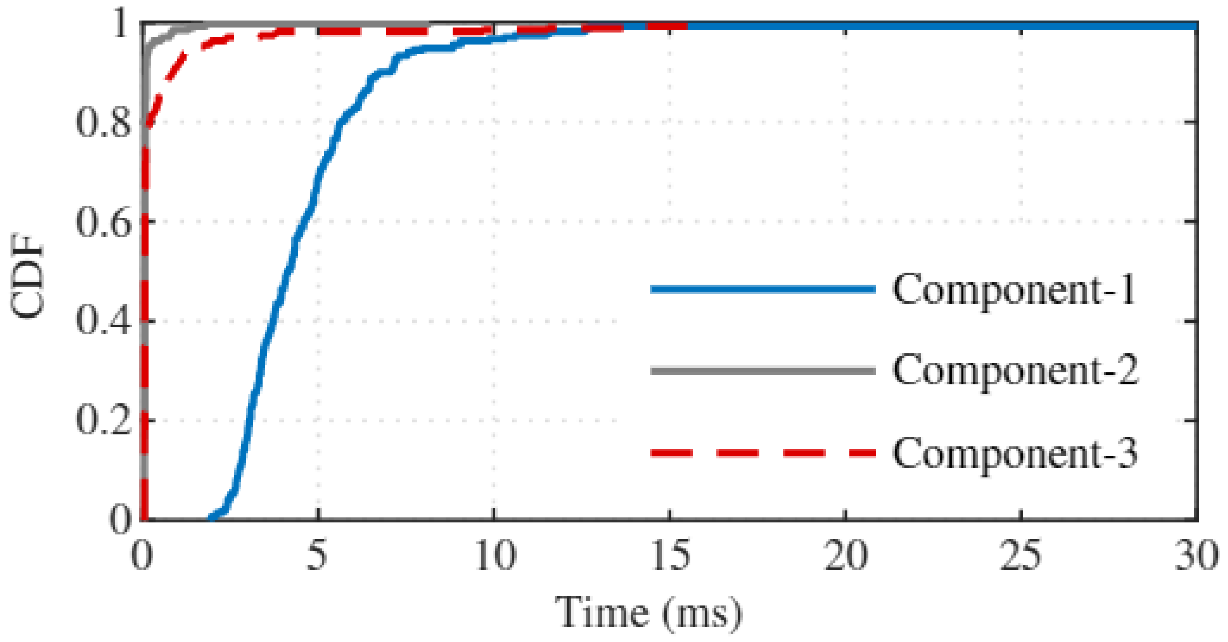
System accuracy



Overall performance

- ShakeReader achieves the matching accuracy of >94.6% in the case of multi-user interaction
- The accuracy of ShakeReader reaches 96.9% and FRR is 2% under shelf scenario.

System latency



Execution time of each key component in ShakeReader

- the average processing time is 7.6ms for each smartphone gesture matching, which is acceptable for most interaction applications.

Conclusion

- We propose the ShakeReader to bridge the gap between customers and RFIDs without making any hardware extension.

- We propose the reflector polarization model and design an interactive smartphone gesture.

- We implement ShakeReader on the COTS devices and it can accurately pair interested tags with their corresponding smartphones with an accuracy of >94.6%.

Thank you!

kaiyan.cui@connect.polyu.hk