IEEE INFOCOM

# ShakeReader: ‘Read’ UHF RFID using Smartphone

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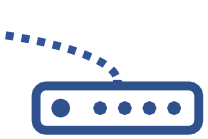
# Background: RFID for Retailers

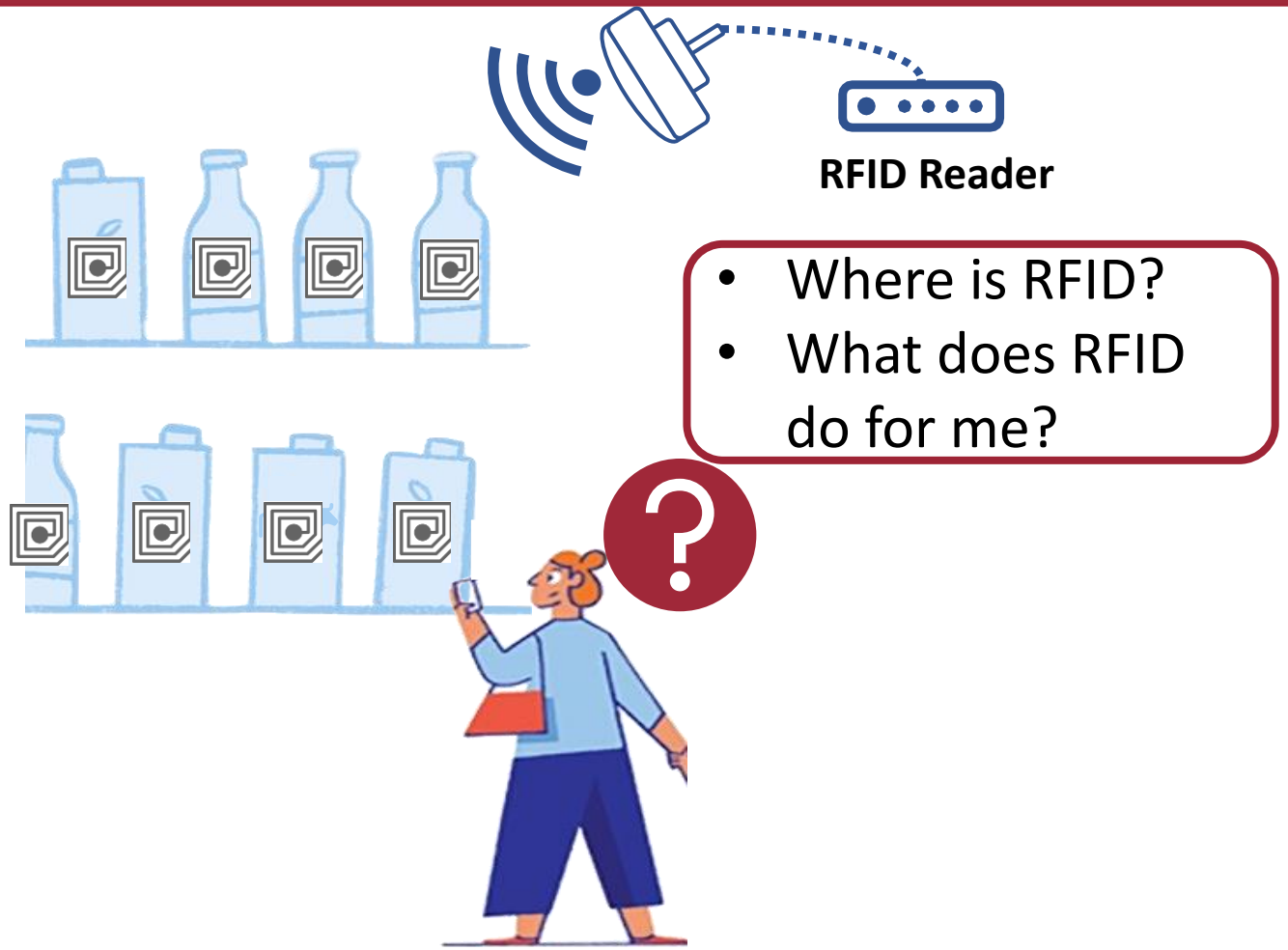
**RFID Reader**

## Importance for retailers

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

**Retailers can benefit tremendously from RFIDs.**

# Background: RFID for Customer

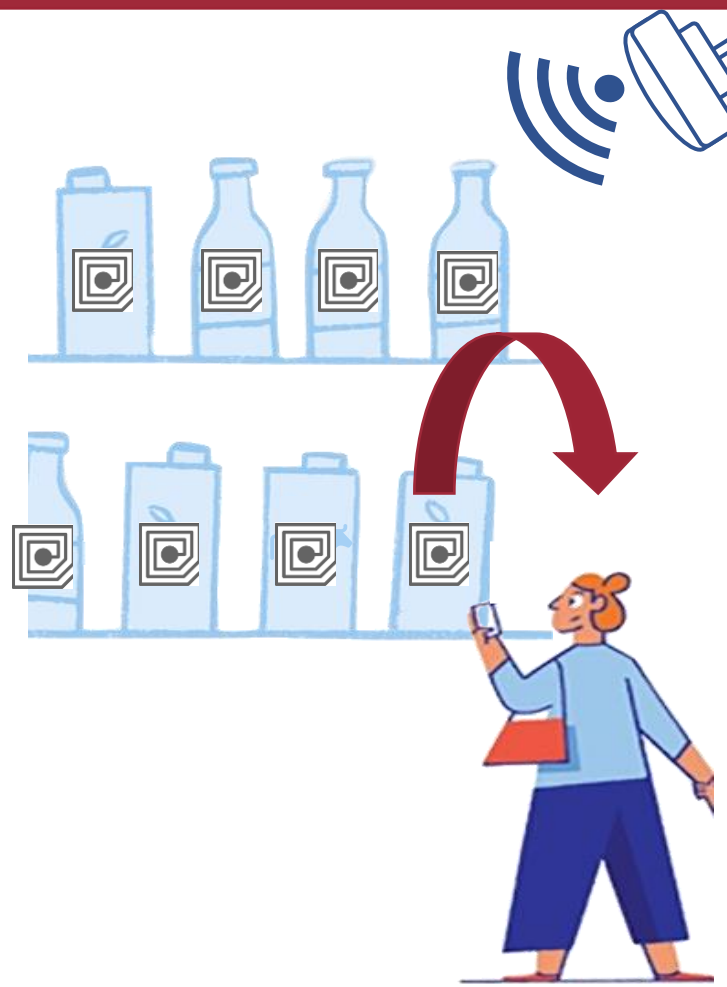



- Where is RFID?
- What does RFID do for me?


- 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:**

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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
  - \+ ….

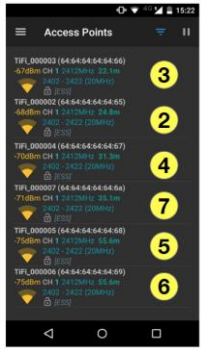
**We aim to enable customers to ‘read’ RFID tags by bridging the gap between the deployed RFID infrastructure and smartphones**

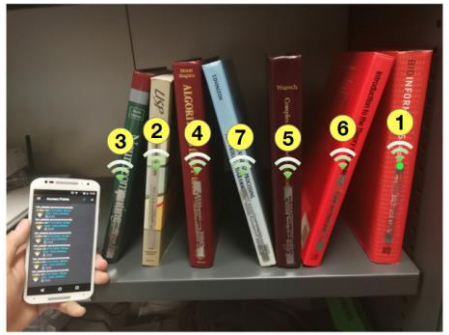
# Existing Solutions

❖Handheld readers


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

❖Cross-technology communication[1]



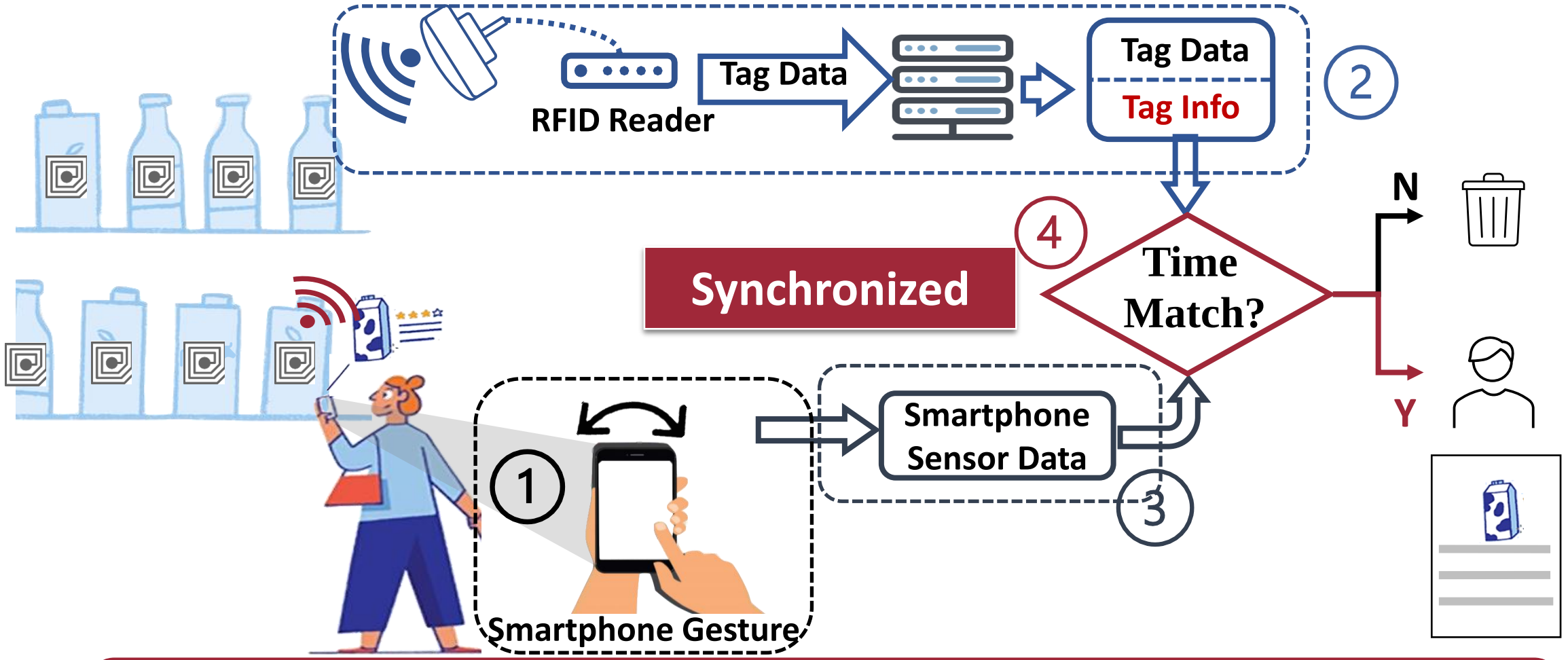

- Do not support one-to-one interaction

**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

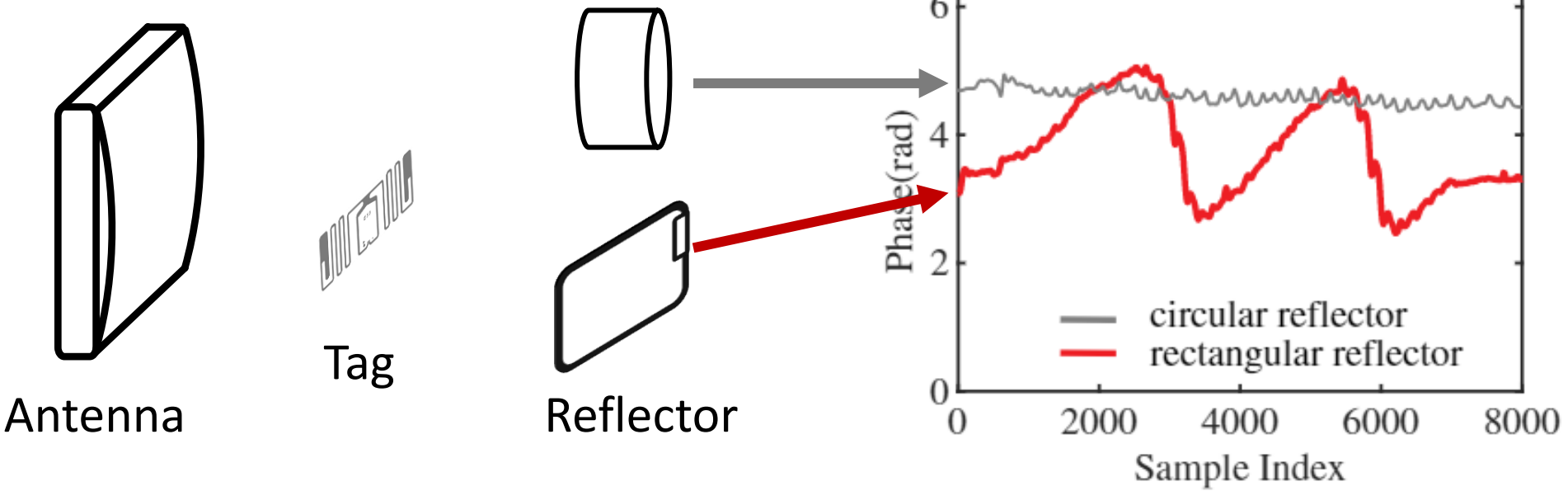

**In our scenario:**

- 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

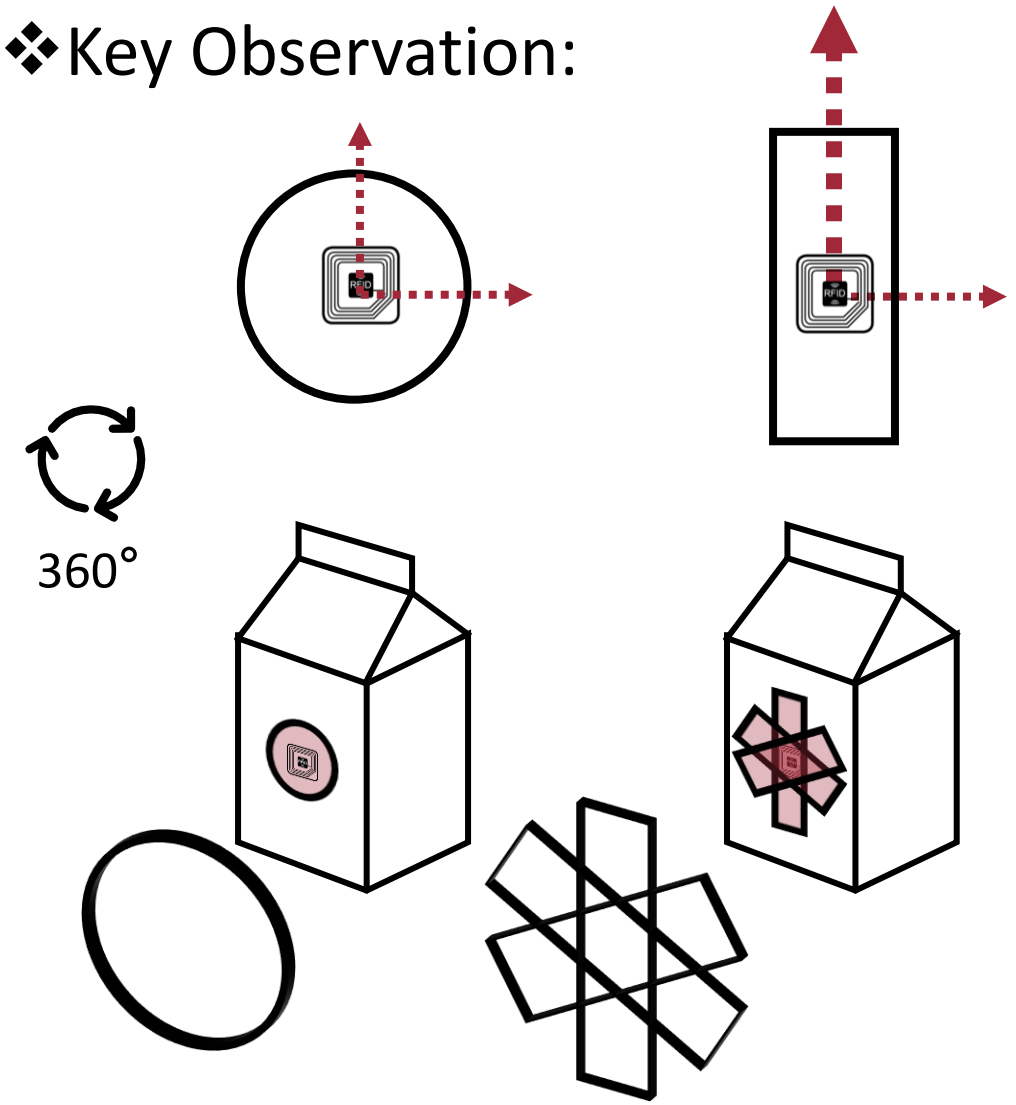
❖Key Observation:




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

# Solution: Reflector Polarization

❖Key Observation:

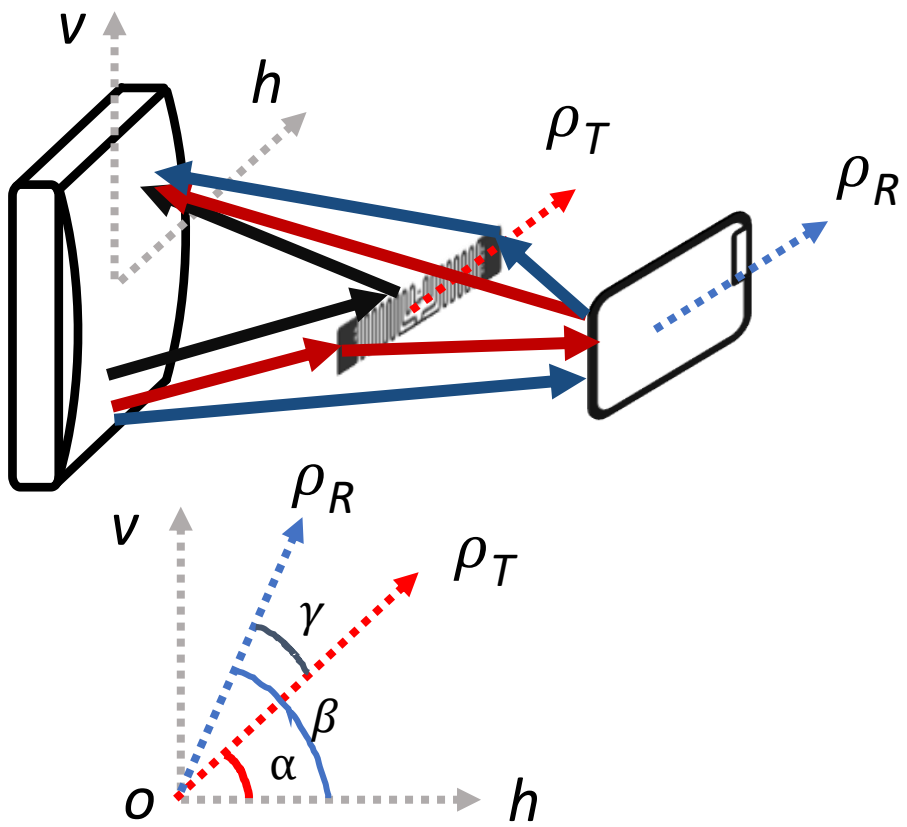



- differences in length and width of the reflectors
- the signal reflected along the long axis dominates the reflected signal strength

**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:

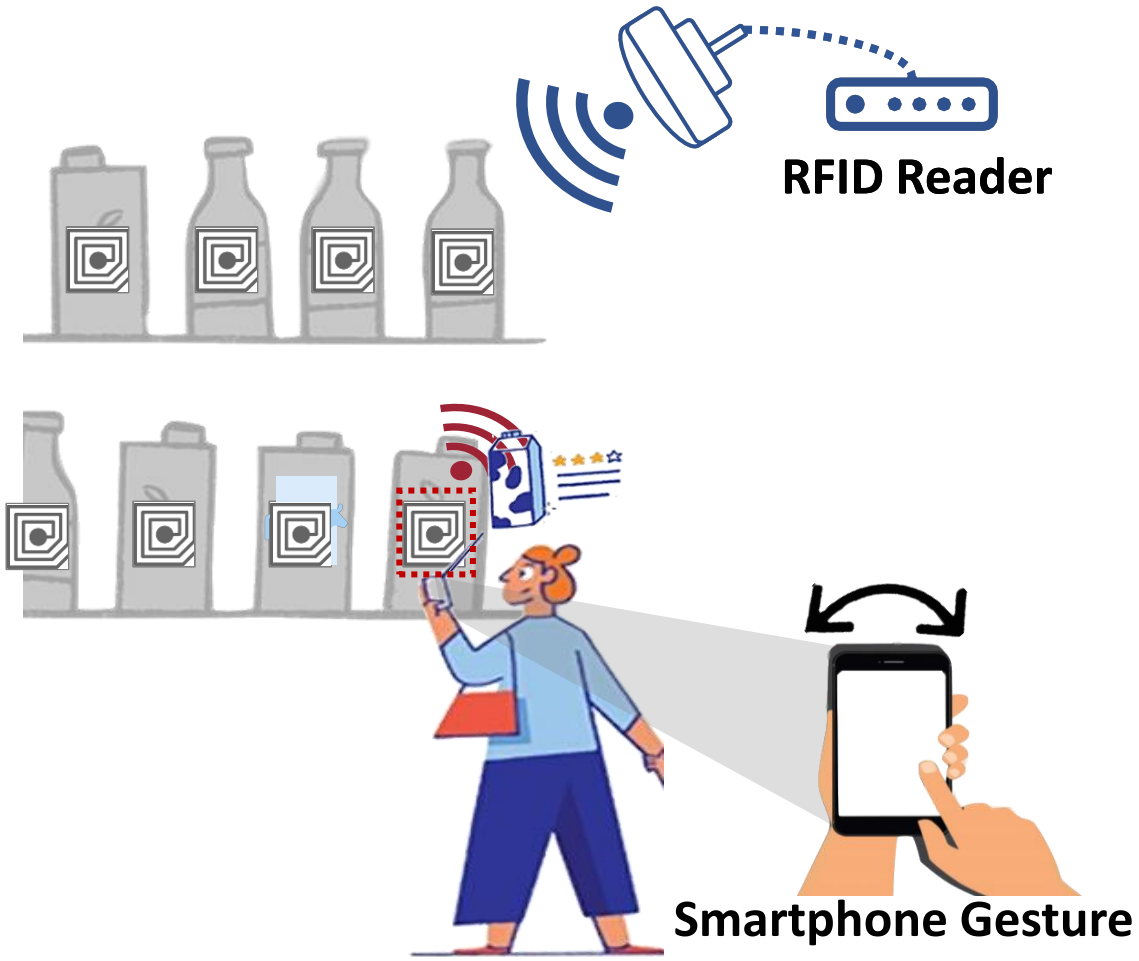


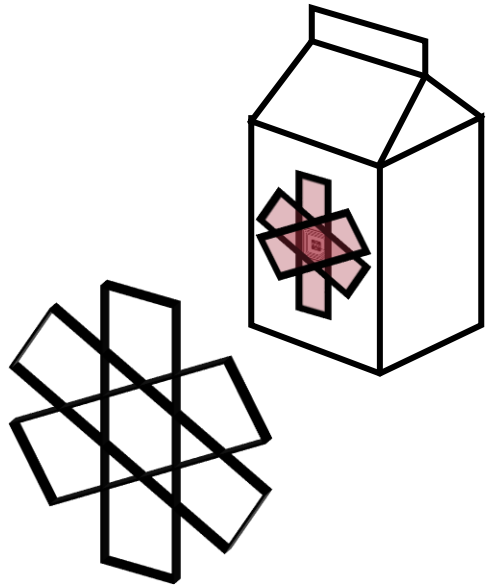

- Received Signal R(t)
  1. Antenna-Tag- Antenna
  2. Antenna-Tag-Reflector-Antenna
  3. Antenna-Reflector-Tag-Antenna

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

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

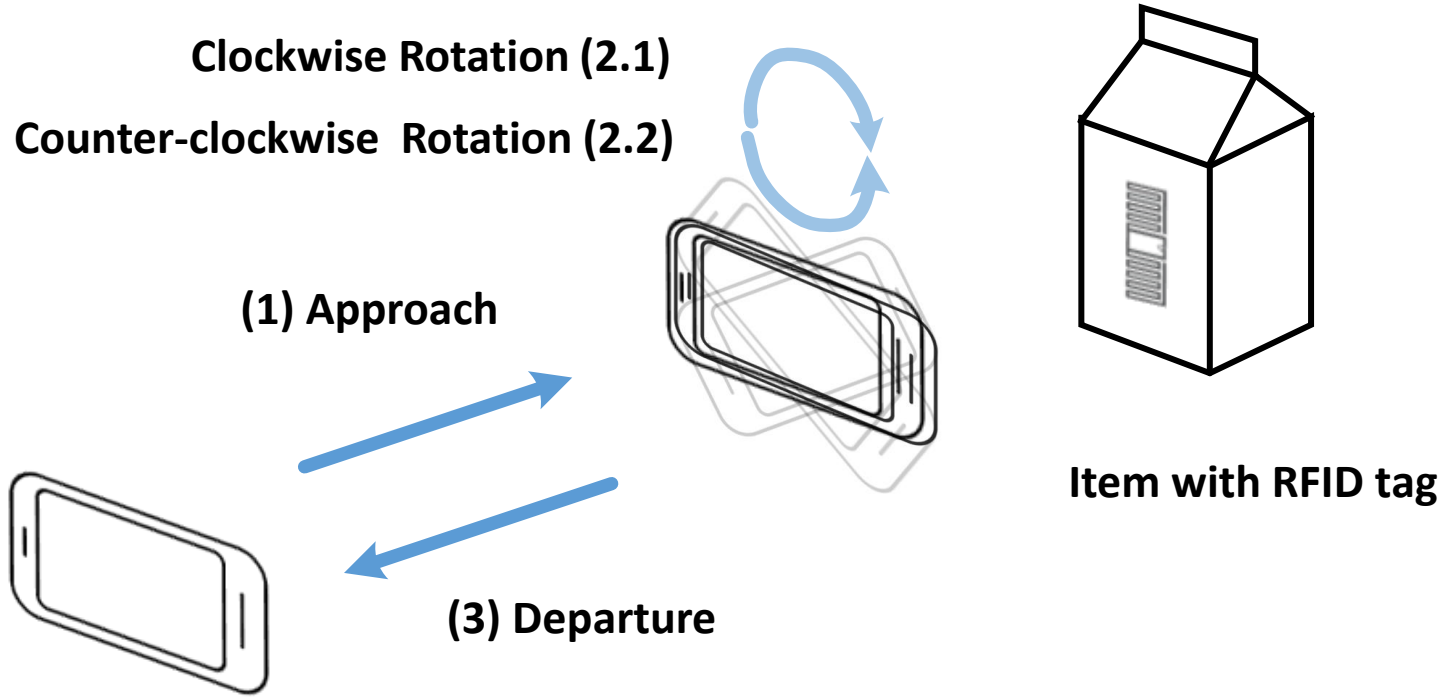
# Solution: Reflector Polarization



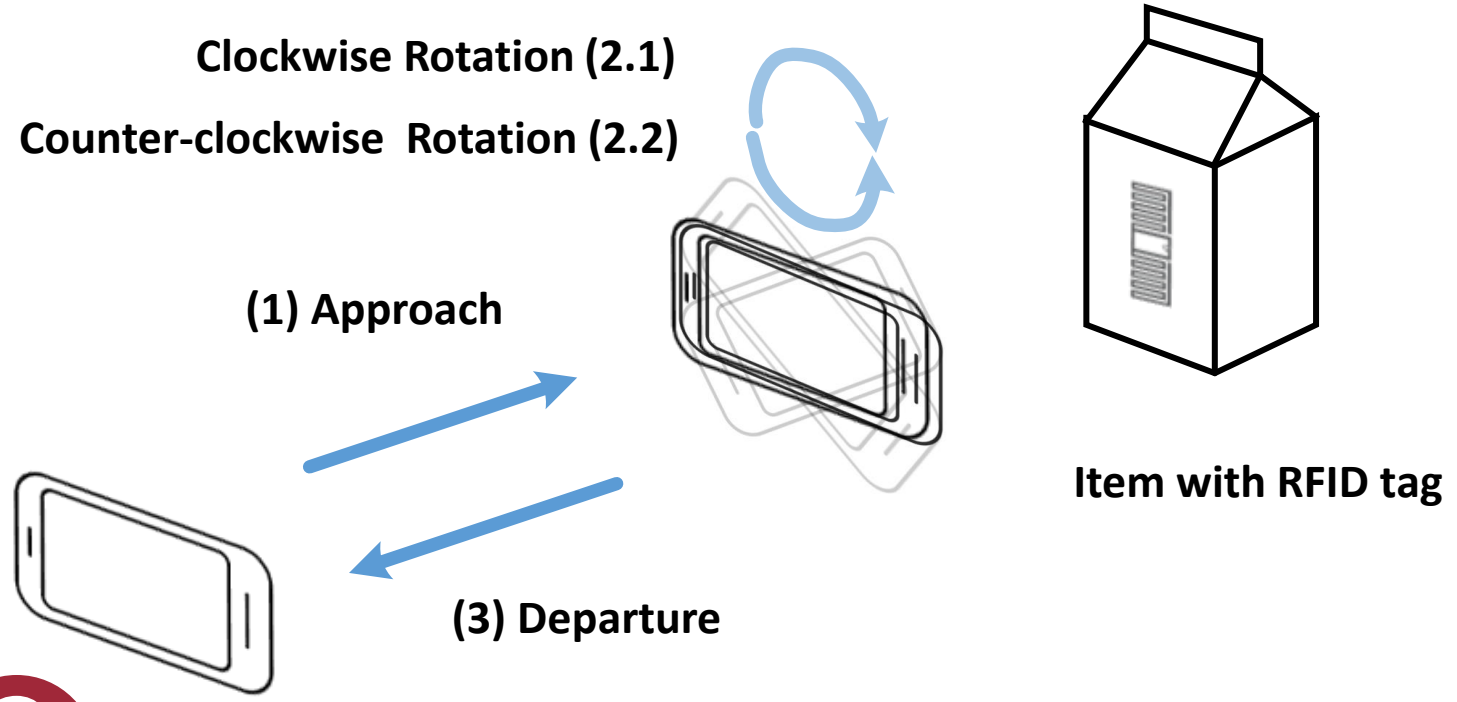
We leverage the smartphone rotation as the interactive gesture to specify user's interest in a static tag.

# Smartphone Gesture



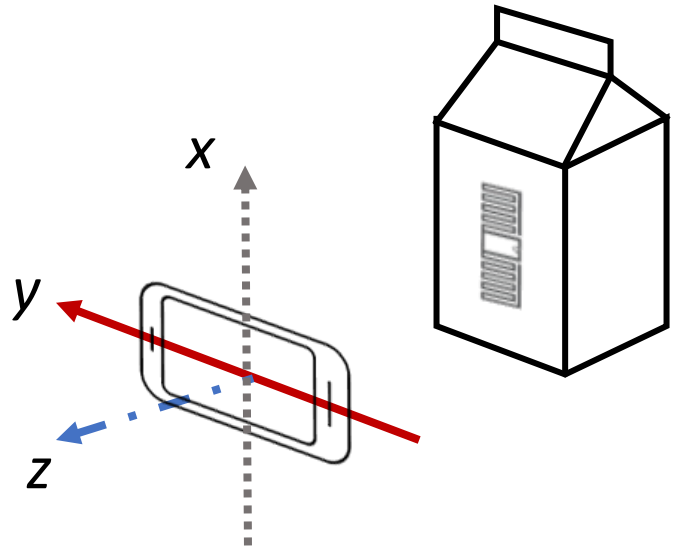

**We design a combined gesture to prevent the influence of other human activities**

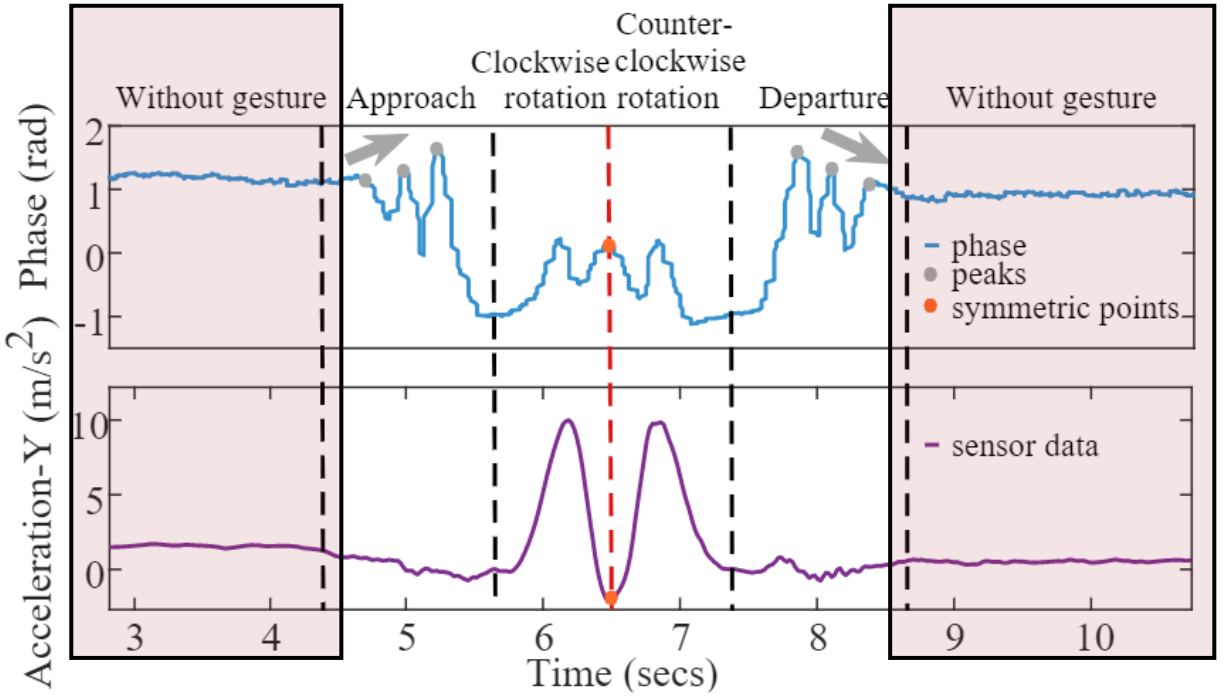
# Smartphone Gesture




**How to detect this smartphone gesture?**

# Smartphone Gesture Detection

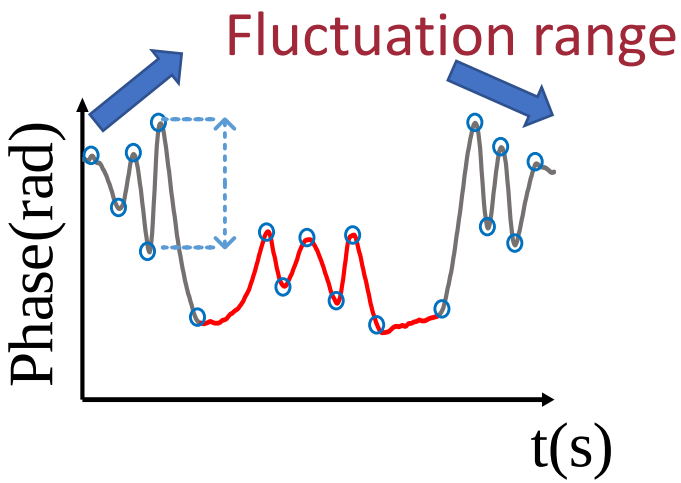


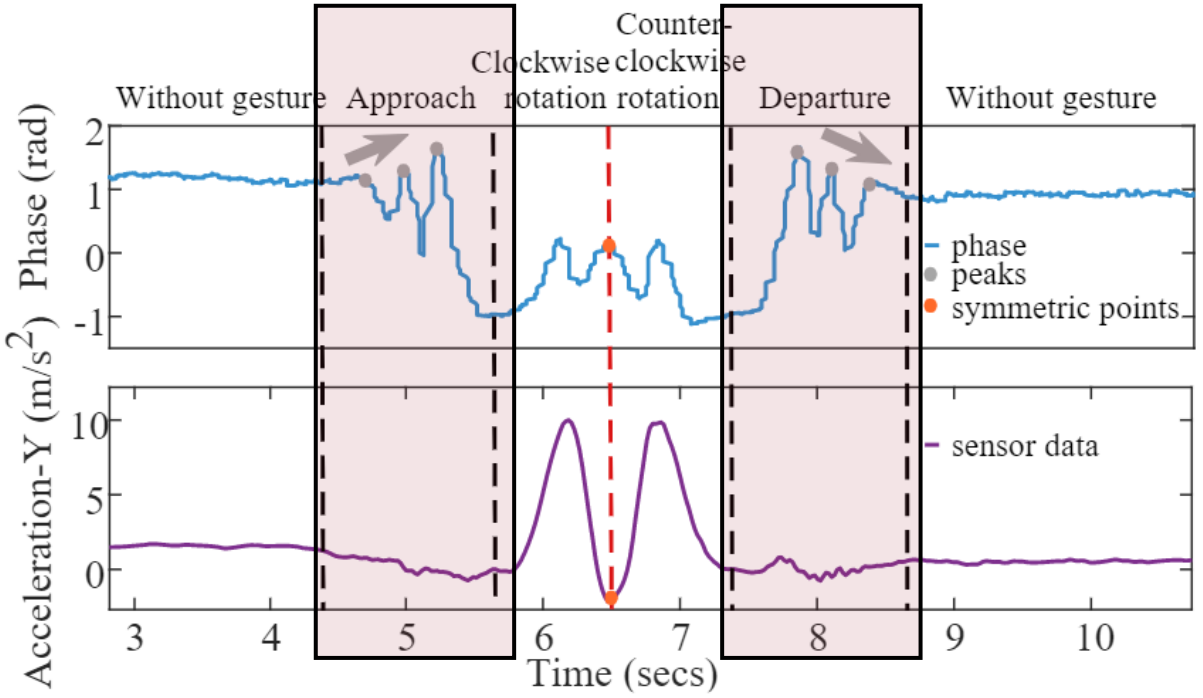

**1) Starting Point and Finishing Point Detection:** measure the standard deviation of phase and acceleration readings.

**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



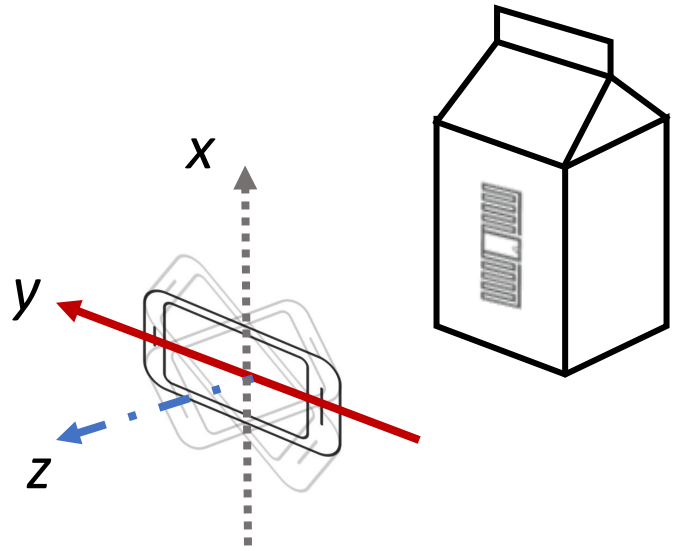

Fluctuation range: the difference between two adjacent local maximum and local minimum.

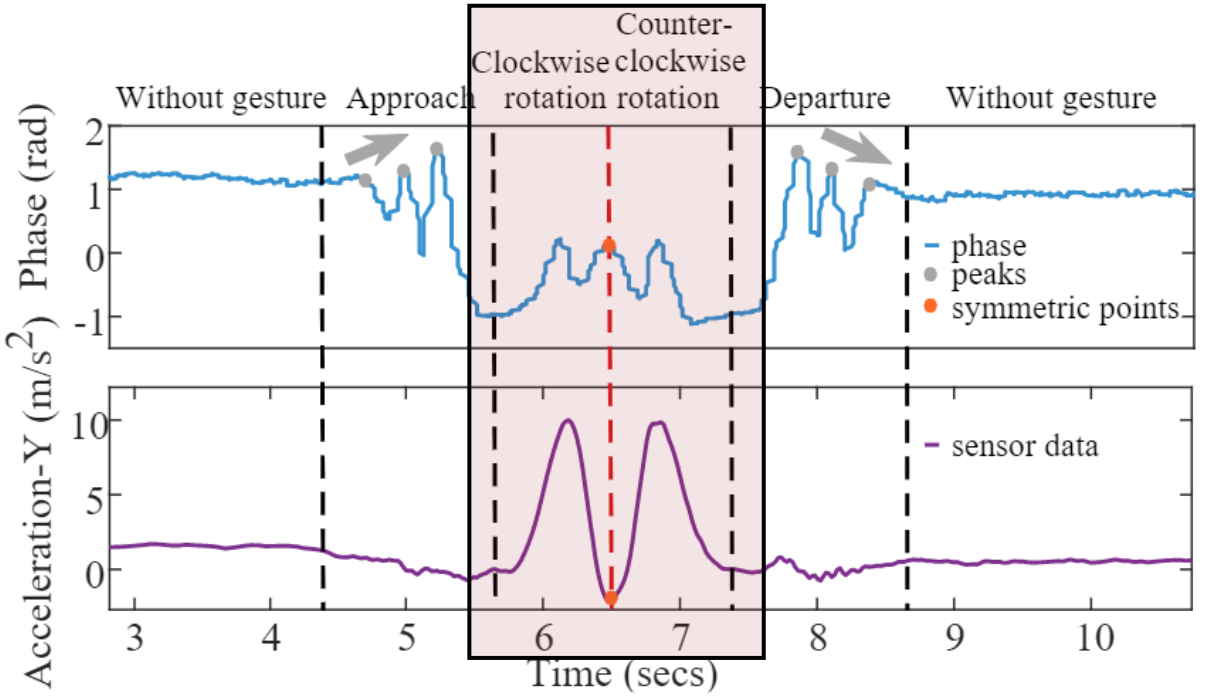



**1) Starting Point and Finishing Point Detection:** measure the standard deviation of phase and acceleration readings.

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

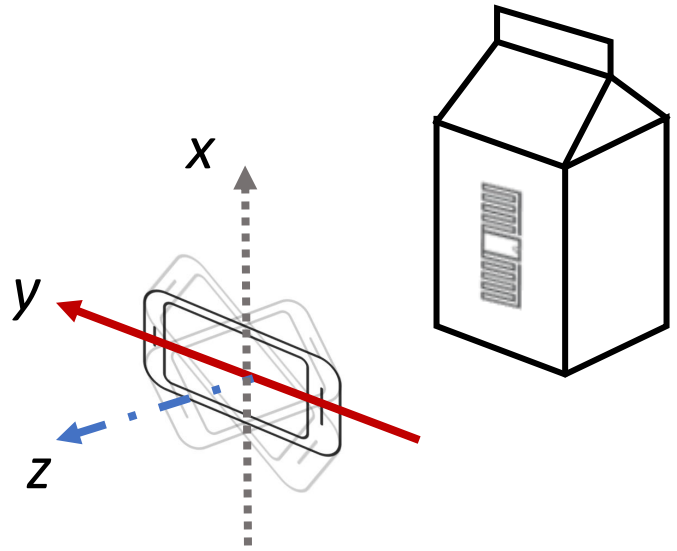
# Smartphone Gesture Detection

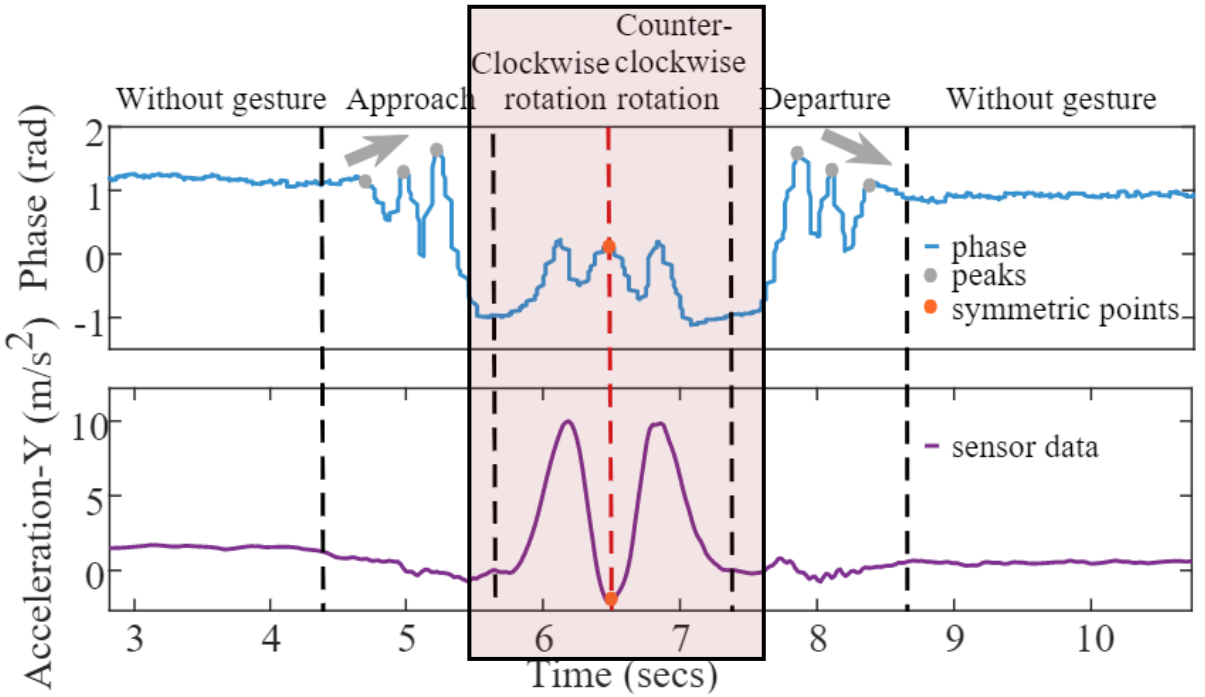



**3) Rotation Detection:** phase values: 'W' shape. Acceleration-Y readings: 'M' shape. We utilize DTW algorithm to detect this symmetric rotation.

# Smartphone Gesture Detection

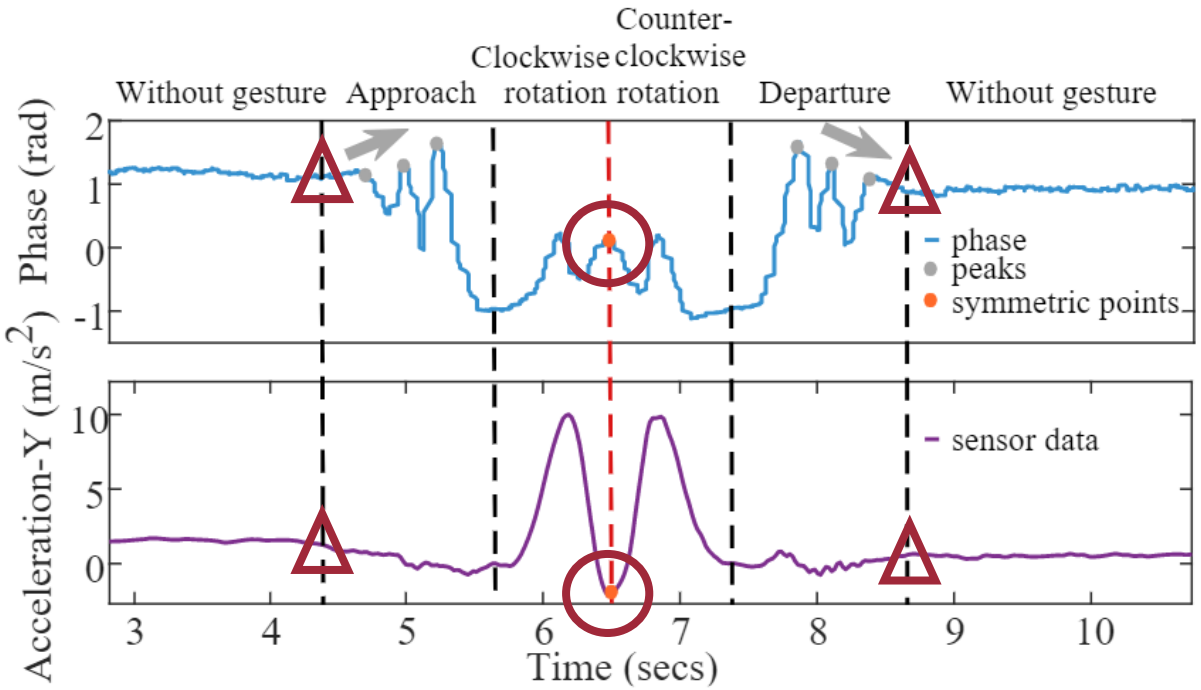



**How to match the interested tag with its corresponding smartphone user?**

# Matching

- Synchronicity between RFID data and sensor data



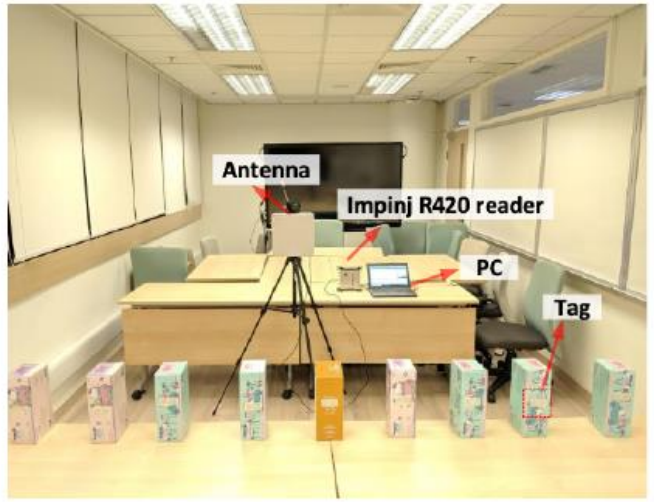

**Three key timing information:**

- 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

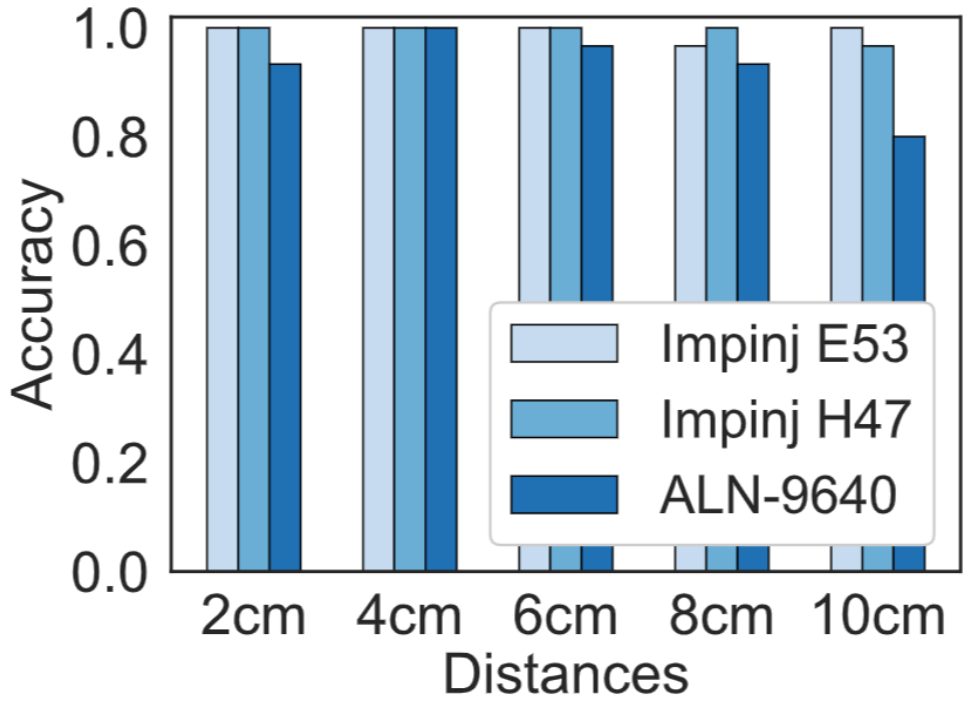
- Experimental Scenarios:
  - typical office room
  - a shelf Scenario
- Hardware:
  - Impinj R420 reader
  - Larid antenna A9028
  - three kinds of commercial tags
  - three kinds of smartphones with different materials
- Metrics:
  - Accuracy
  - False Accept Rate (FAR)
  - False Reject Rate (FRR)




# 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

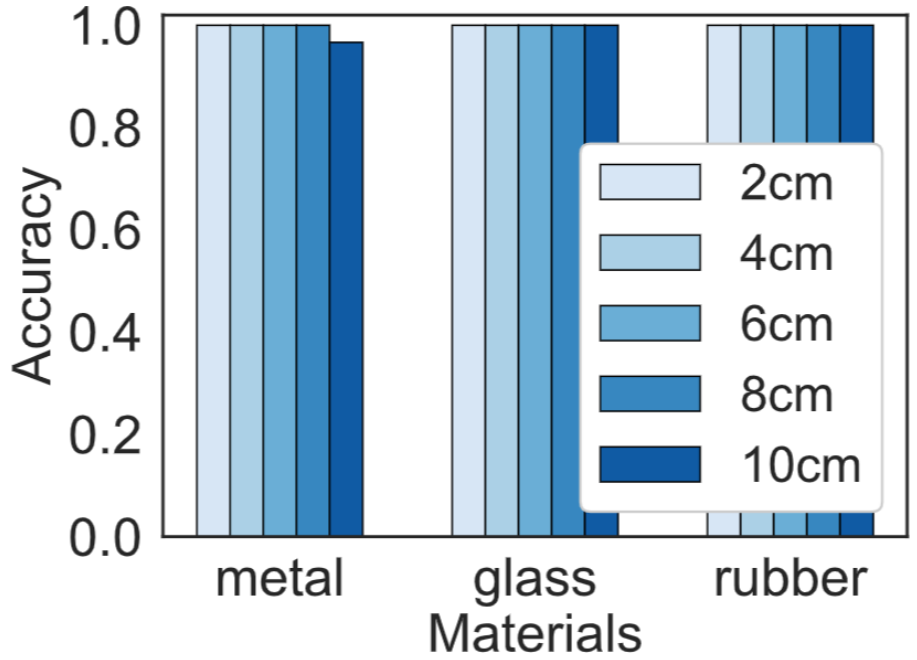
# Impact of smartphone-to-tag distance




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

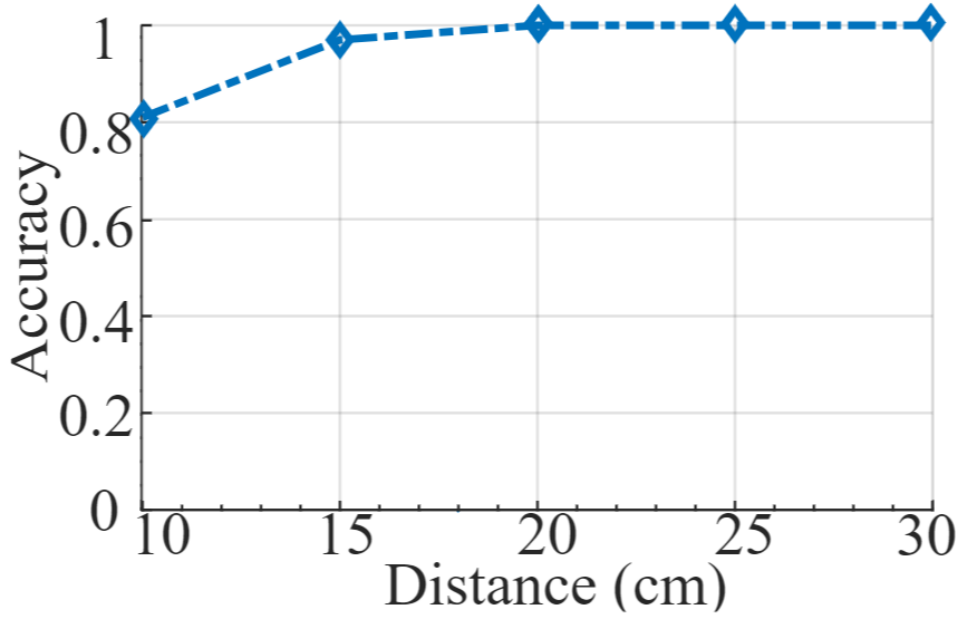
# Impact of smartphone materials




Detection accuracy of different smartphone materials

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

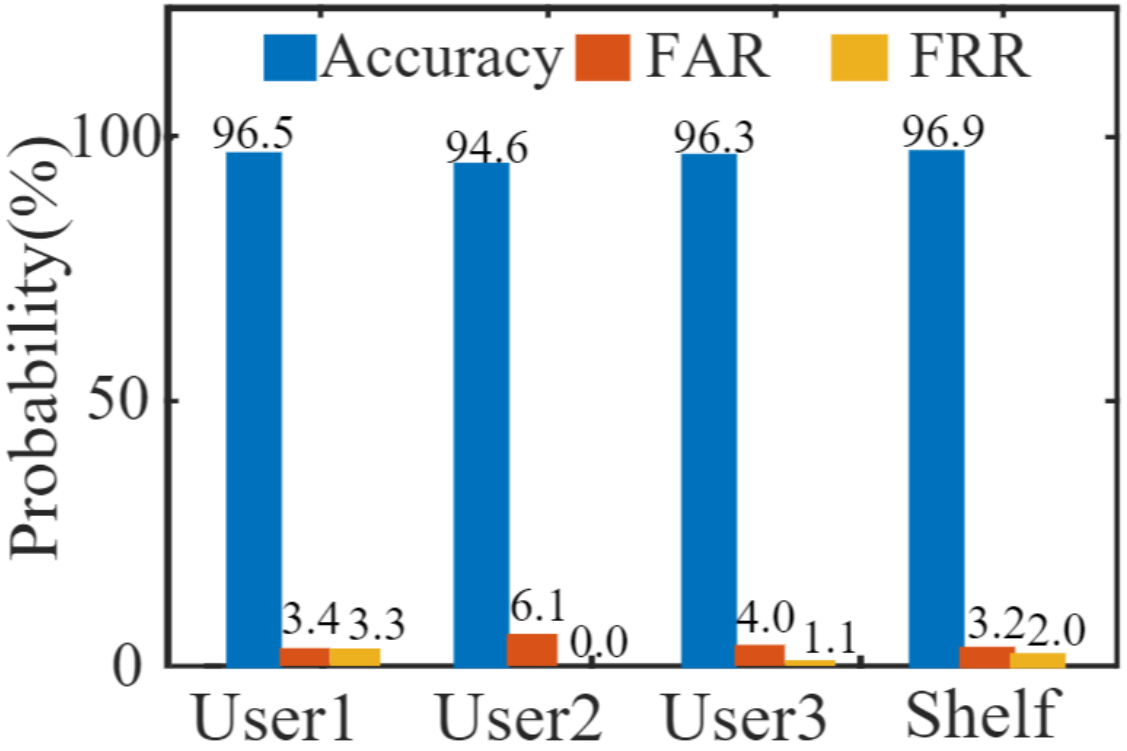
# Impact of tag-to-tag distance




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.

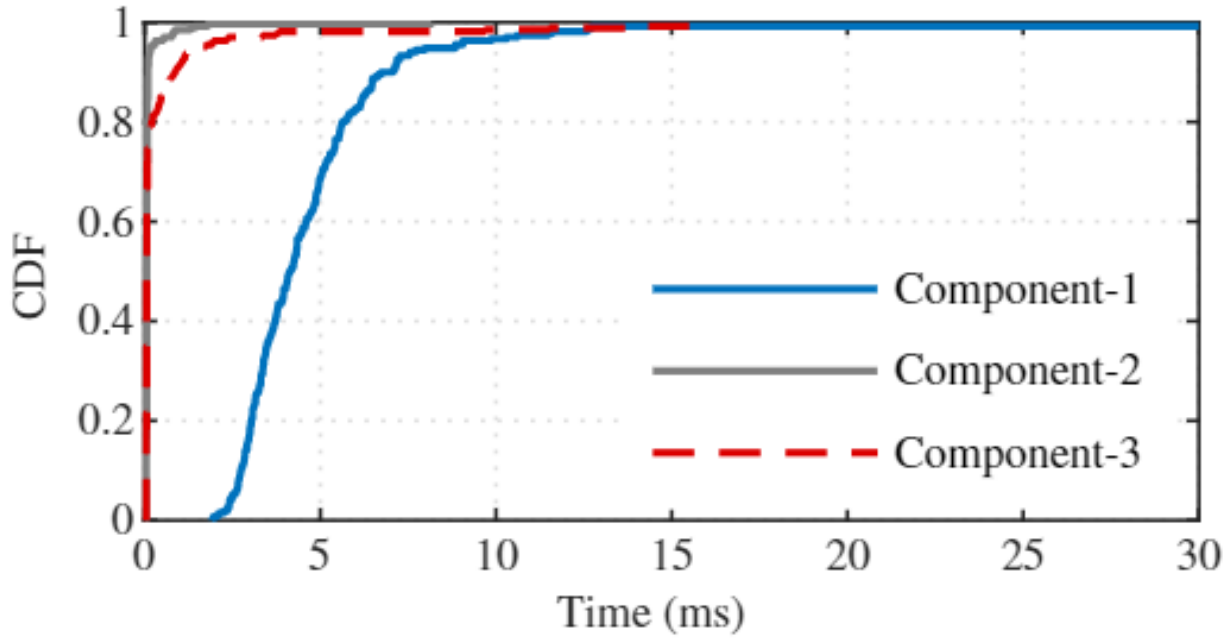
# System accuracy




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!

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