ShakeReader: ‘Read’ UHF RFID using Smartphone

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Background: RFID for Retailers

Retailers can benefit tremendously from RFIDs.

- Asset Tracking
- Supply Chain Management
- Automated Inventory
- ...

Importance for retailers
Background: RFID for Customer

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

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

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

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
  + ....
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.

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

Key Observation:

The rotating polarization of rectangular reflector will affect the tag’s phase values, even though both tag and antenna remain static.
Reflector Polarization Model:

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

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

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

Clockwise Rotation (2.1)
Counter-clockwise Rotation (2.2)

(1) Approach

(3) Departure

Item with RFID tag

How to detect this smartphone gesture?
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.
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.

Fluctuation range: the difference between two adjacent local maximum and local minimum.
3) **Rotation Detection**: phase values: ‘W’ shape. Acceleration-Y readings: ‘M’ shape. We utilize **DTW algorithm** to detect this symmetric rotation.
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
• Almost all the gestures performed using smartphones with different back cover materials can be detected.
Impact of tag-to-tag distance

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