RIO: A Pervasive RFID-based Touch Gesture Interface

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MobiCom 2017
LOTS of Connected Devices by 2020
LOTS of Connected Devices by 2020

~30 Billion*
Smart Spaces
Smart Spaces

Smart Hospitals

Smart Offices

Smart Retail
Can we effectively transform everyday objects into a touch interface?
Wireless

Capacitive

Vision

IMU
Issues with these modalities
Issues with these modalities

• Not easy to customize

• Not low cost

• Extensive training phase

• Need to be recharged frequently ...
Passive RFID tags as touch interface
Passive RFID tags as touch interface

COTS Tags

Custom Tags

COTS Reader/Antenna
And that interface ...
And that interface ...

• Customizable and less costly
• Battery-free
• Supports fine-grained tracking
• Multi interface support
Key Idea and Reasoning

Touch and Single Tag Tracking

Tracking within Multiple Tags

Evaluation
Key Idea and Reasoning

- Touch and Single Tag Tracking
- Tracking within Multiple Tags
- Evaluation
Predictable phase change at reader side

Antenna

Reader

Tag

Finger Swipe on Tag
Why does it happen?
Why does it happen?
Why does it happen?
Why does it happen?
Why does it happen?
Why does it happen?

Backscattered Electric field and Phase

Induced Current $\propto \frac{Z_{\text{chip}} + Z_{\text{Antenna}}}{\text{Incident Electric Field}}$
VNA based measurements
VNA based measurements
VNA based measurements
VNA based measurements
VNA based measurements
Key Idea and Reasoning

Touch and Single Tag Tracking

Tracking within Multiple Tags

Evaluation
How to detect touch?
How to detect touch?
How to detect touch?

Sudden Jump in Phase
How to detect tracking?

![Graph showing relationship between phase and position on the tag.](image.png)
How to detect tracking?
How to detect tracking?

Predictable Phase Pattern
This change is also present in NLoS
This change is also present in NLoS

Behind a Wall

Behind a Door
This change is also present in NLoS

Remains Similar

Behind a Wall

Behind a Door
Single tag tracking algorithm sketch
Single tag tracking algorithm sketch
Single tag tracking algorithm sketch
Single tag tracking algorithm sketch

Calibration Phase

Phase

Last Known Position
Single tag tracking algorithm sketch

Phase

T-second Swipe Phase

Last Known Position

Calibration Phase
Single tag tracking algorithm sketch

Phase

T-second Swipe Phase

Last Known Position

Calibration Phase
Single tag tracking algorithm sketch

- **Phase**
  - T-second Swipe Phase
  - DTW Matching
  - Calibration Phase

- **Position**
  - Last Known Position
  - Potential New Position
Key Idea and Reasoning

Touch and Single Tag Tracking

Tracking within Multiple Tags

Evaluation
Tracking within Multiple Tags
Tracking within Multiple Tags
Mutual coupling phenomenon
Mutual coupling phenomenon

Neighboring tags show reverse phase pattern.
Why does it happen?
Why does it happen?
Why does it happen?

Coupled mutual impedance has reverse impact in back-scattered phase
Multi tag tracking algorithm sketch
Multi tag tracking algorithm sketch
Multi tag tracking algorithm sketch

Apply joint DTW matching
Key Idea and Reasoning

Touch and Single Tag Tracking

Tracking within Multiple Tags

Evaluation
Experimental Setup
Experimental Setup

- Camera
- RFID Tag
- Antenna
- Reader
- Laptop (Processing)
Single Tag Tracking Accuracy
Single Tag Tracking Accuracy
Single Tag Tracking Accuracy

Error ~10 mm
Multi Tag Tracking Accuracy
Multi Tag Tracking Accuracy
Multi Tag Tracking Accuracy

Error \sim 18 \text{ mm}
Custom Tag Tracking Accuracy
Custom Tag Tracking Accuracy

Custom Tags
Custom Tag Tracking Accuracy

Custom Tags

Error ~10 mm
Related Works
Related Works

• RFID based gesture recognition – Data-driven learning
  • ShopMiner (SenSys ‘15), FEMO (SenSys ‘15), CBID (ToN ‘16) ...

• RFID tag tracking – Tracks tag movement
  • RF-IDraw (SIGCOMM ‘14), Tagyro (Mobicom ‘16), PolarDraw (CoNext ‘16) ...

• RFID based UI (Closest) – ML on a fixed set of gestures
  • PaperID (CHI 2015), IDSense (CHI 2016) ...
Future works

• Multi-touch tracking

• General 2D gesture tracking

• Tracking in different environment scenarios

• Building customized tags for other use cases
Key takeaways

• Impedance Tracking based Touch Primitive

• Mutual coupling can be exploited

• Custom designed tags may enable different applications
Thanks! Questions?

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