



RF–Mehndi: A Fingertip Profiled RF Identifier

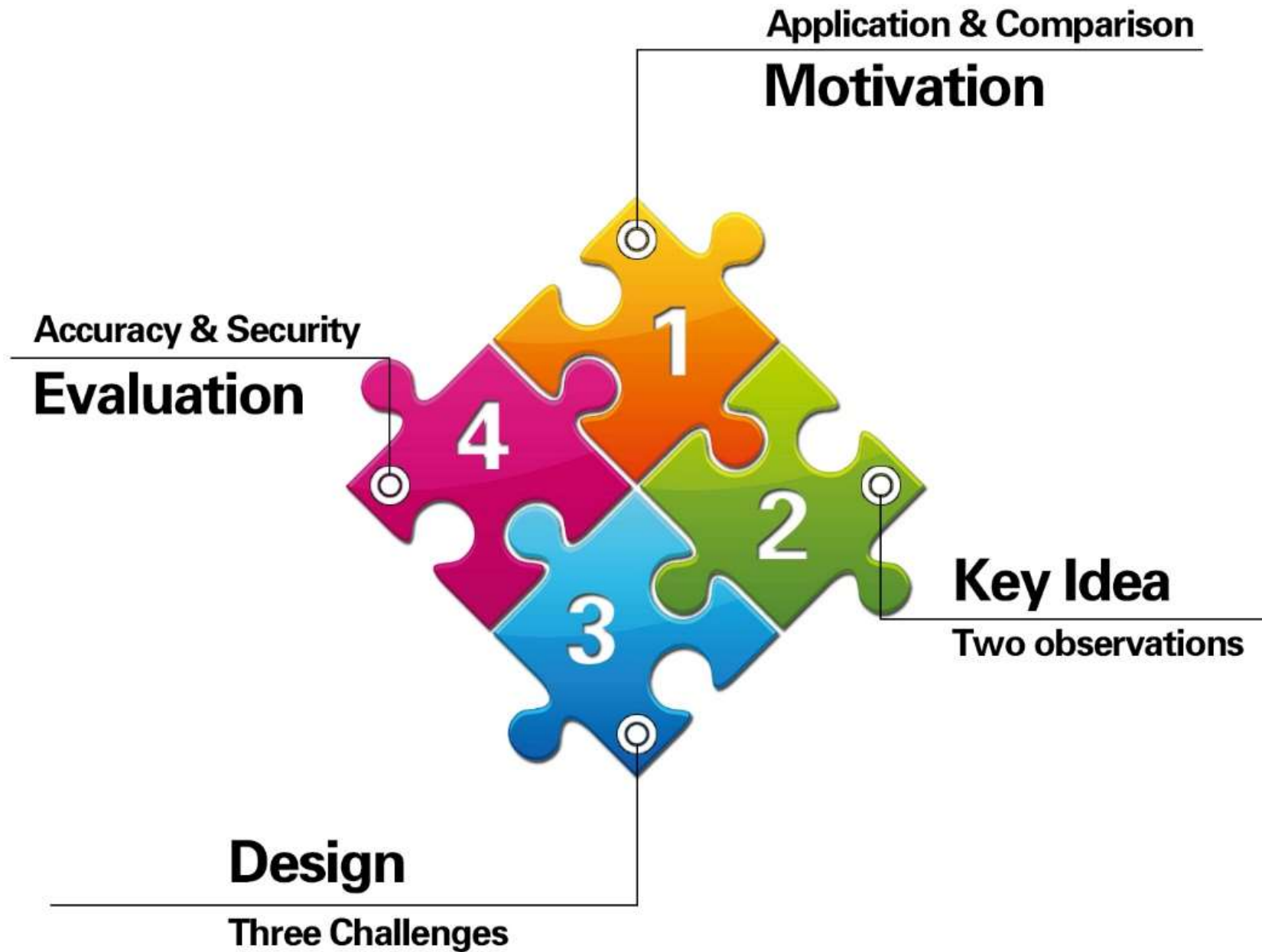
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²City University of Hong Kong, Hong Kong

³Zhejiang University, China







Motivation



Transportation Card



Access Card



Credit Card

Any potential **security risk** with these cards?



Motivation



Thievery



Loss

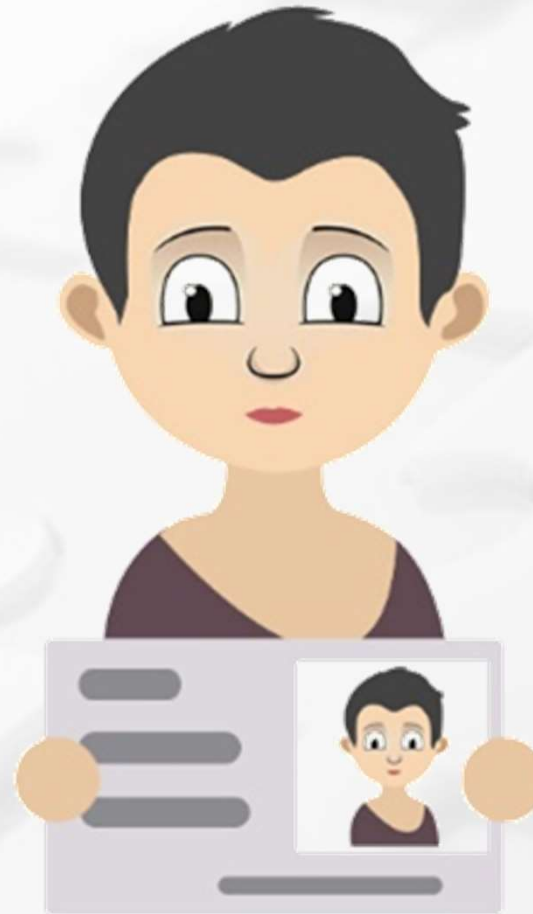
Why can't these cards resist loss and thievery?



Motivation



Sth you have?



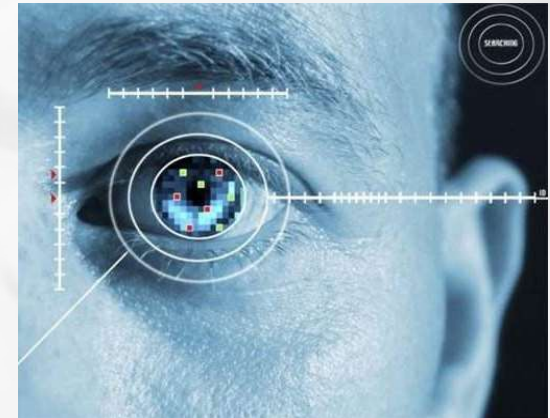
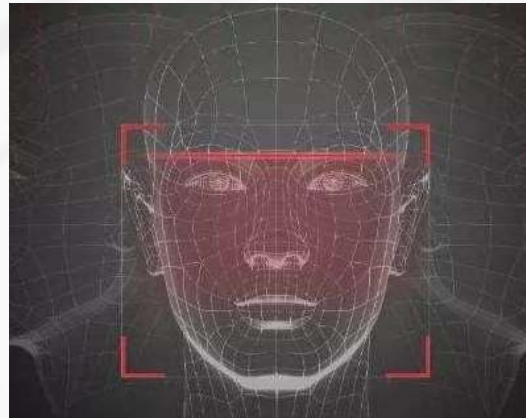
Who are you?



Motivation



Device Authentication



User(Biometric) Authentication



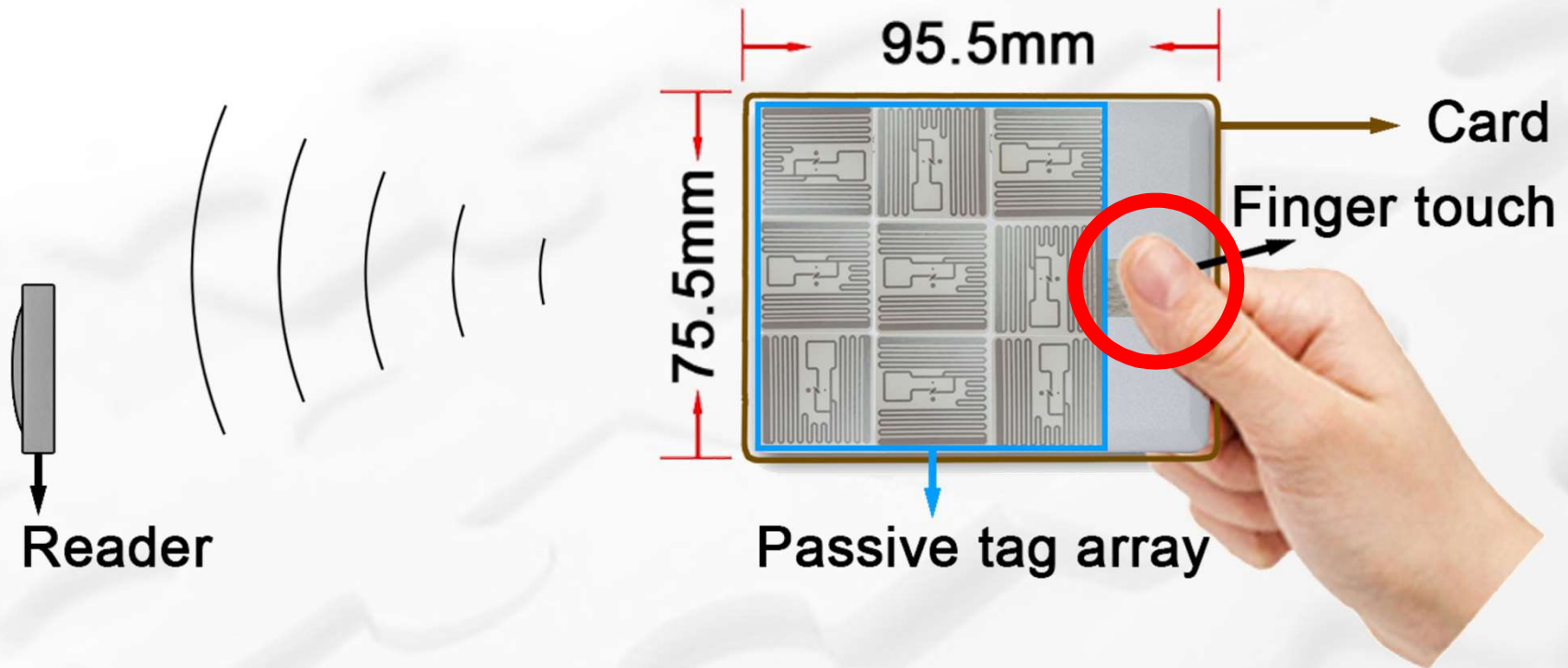
Motivation

Issues with these approaches:

- Not convenient
- Not easy to customize
- Not light-weight
- Not fast to implement
- Not low cost
- ...



Key Idea



User-dependent & Unique



Key Idea

Our goal

Device Authentication



User Authentication

Light-weight

Low-cost

Universal

Counterfeiting

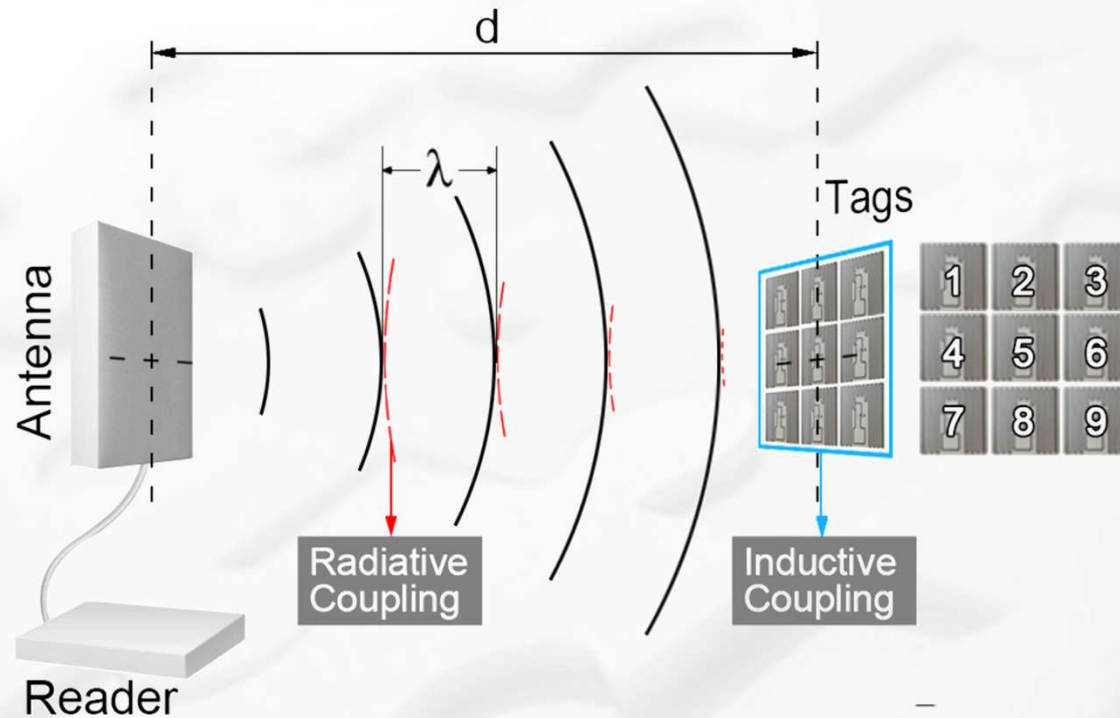
Impersonation

Replay



Key Idea

Radiative & Inductive coupling



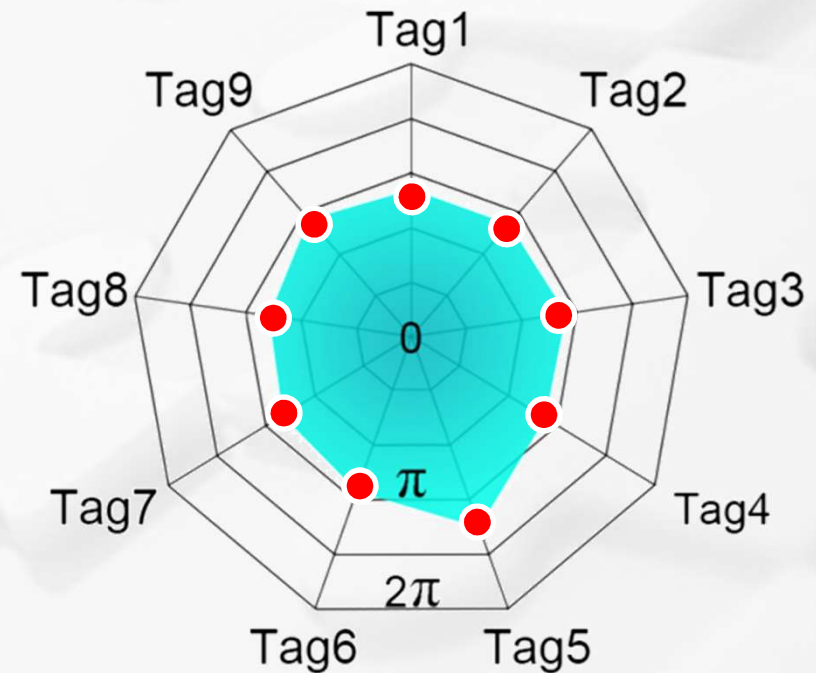
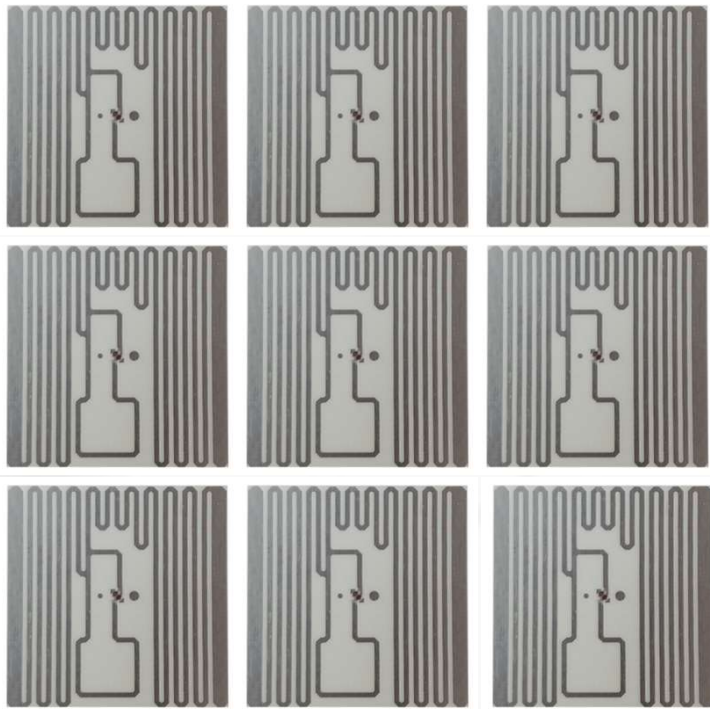
$$\theta = \left(\frac{4\pi d}{\lambda} + \theta_{reader} + \theta_{tag} \right) \mod 2\pi$$



Key Idea

Observation 1 --- Impact of tag coupling

- Tags in a vicinity → Their circuit characteristics change.



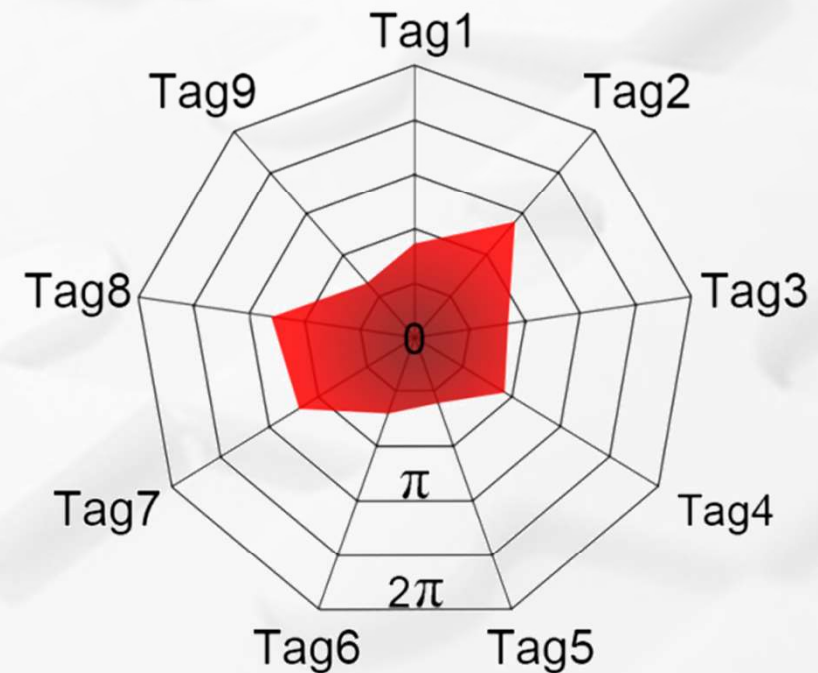
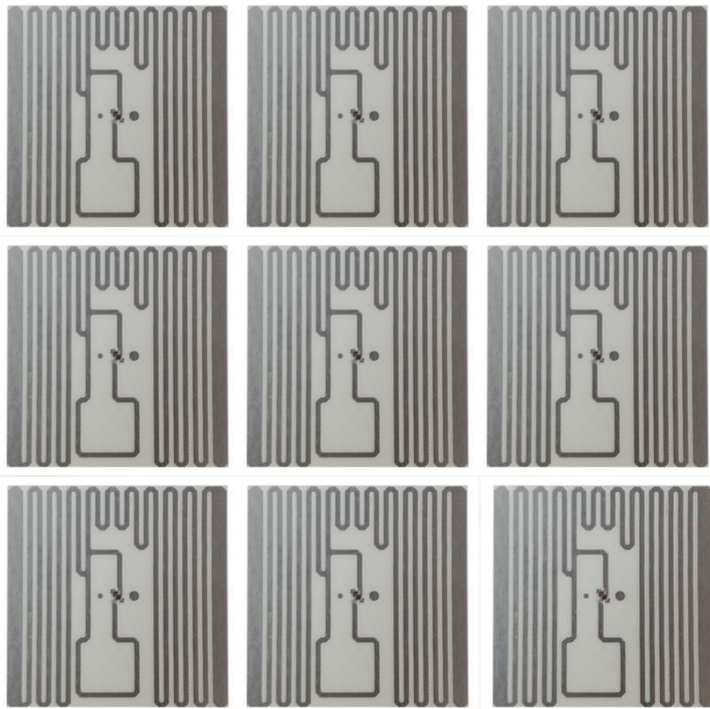
(a) Phase of individual tags ₁₁



Key Idea

Observation 1 --- Impact of tag coupling

➤ What will happen if we collect their phases together?

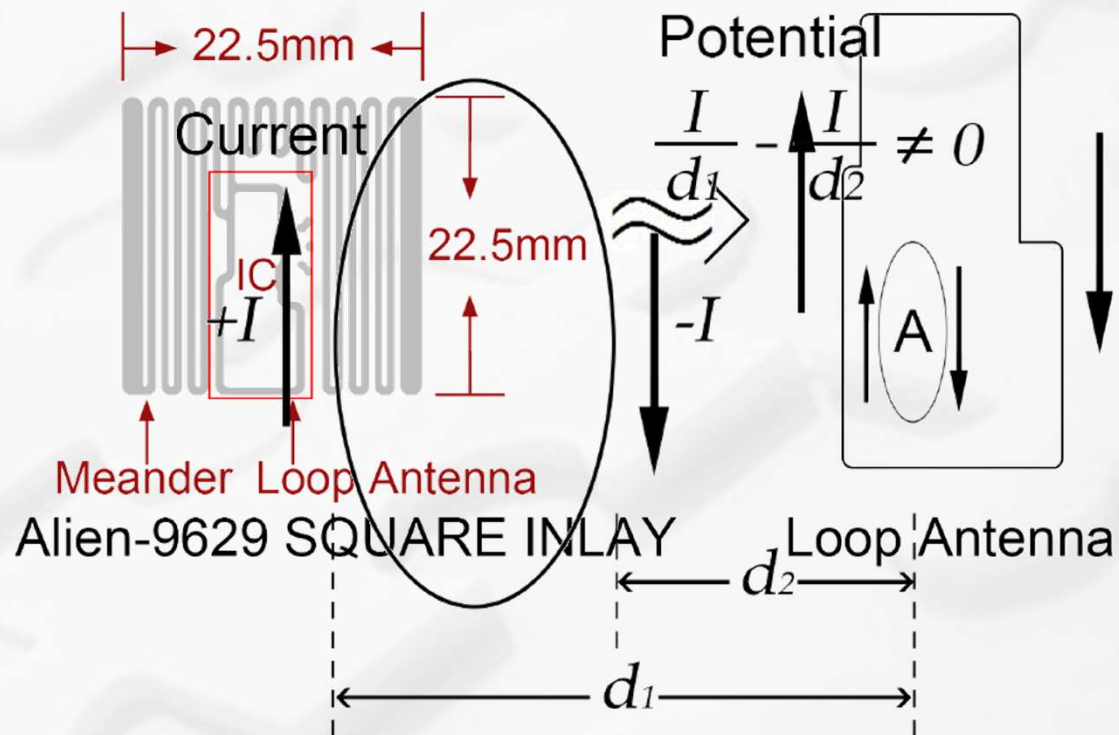


(b) Coupling phase of these tags



Key Idea

Why does the phase change due to coupling?

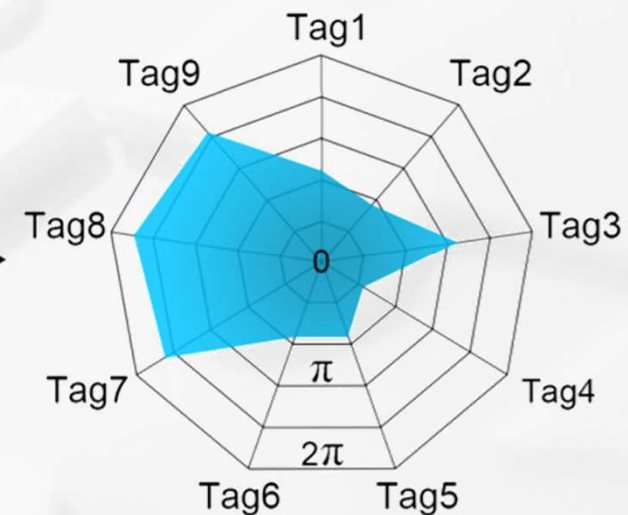
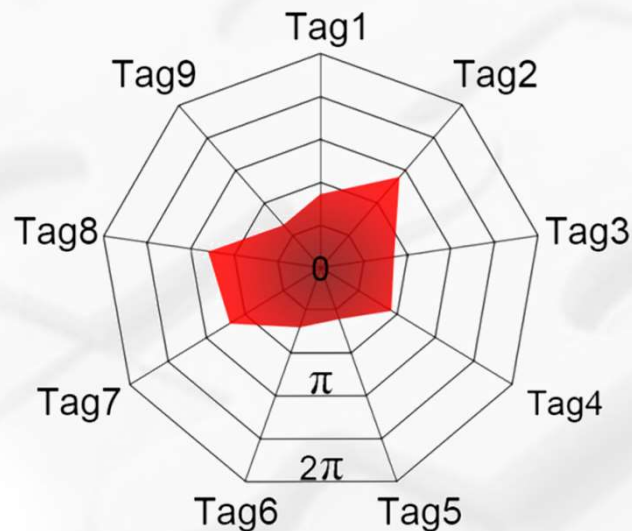
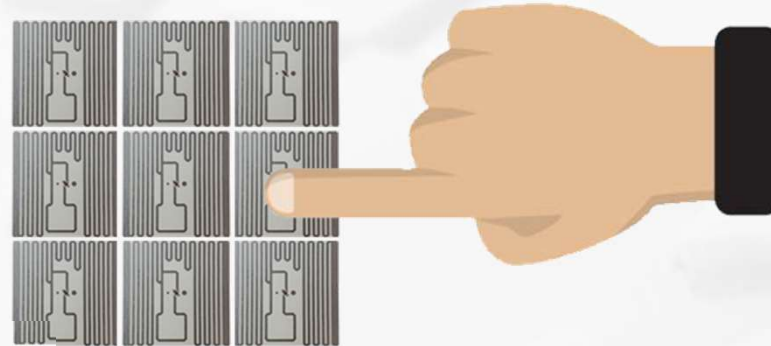




Key Idea

Observation 2

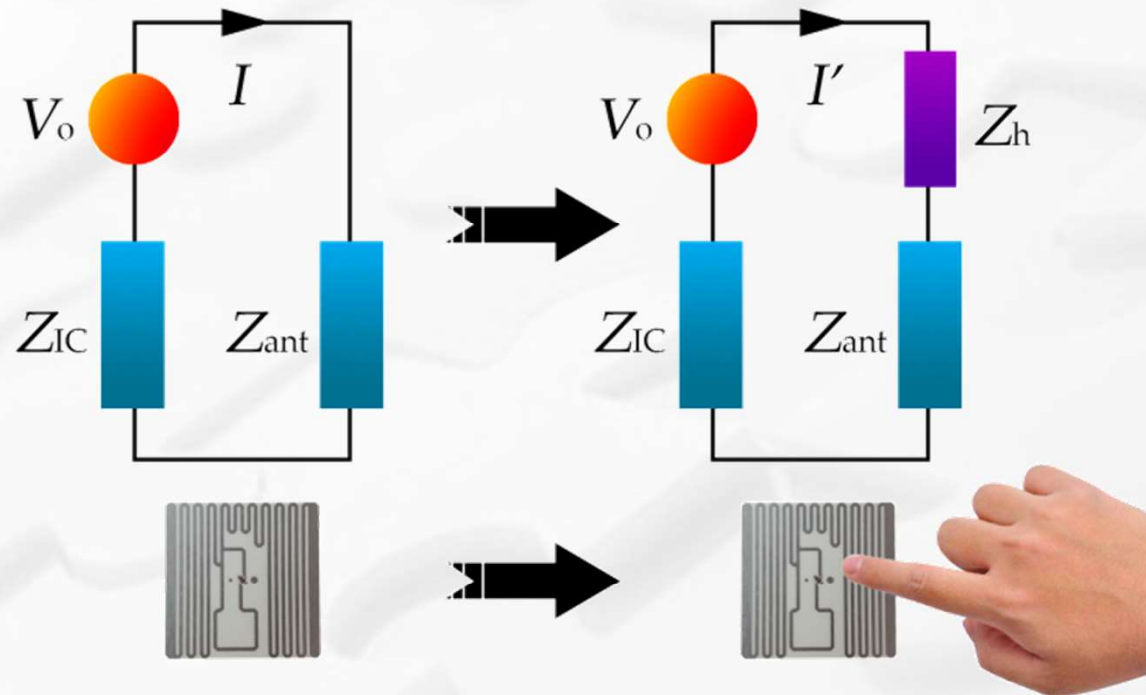
Impact of human impedance





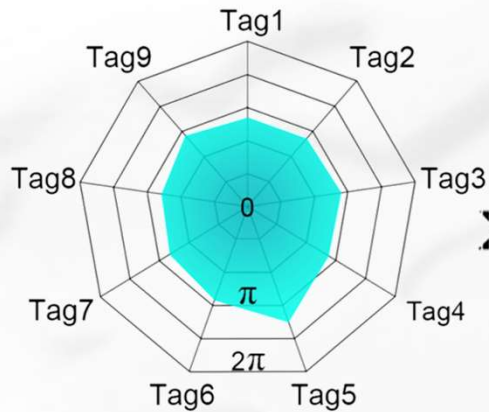
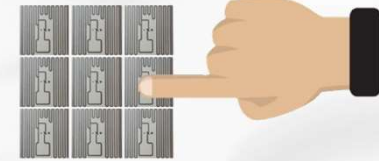
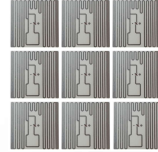
Key Idea

Why does phase change with fingertip touch?

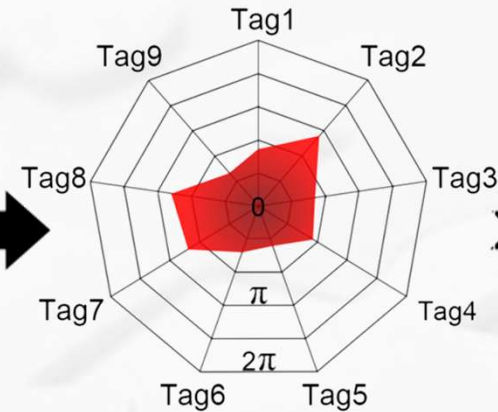




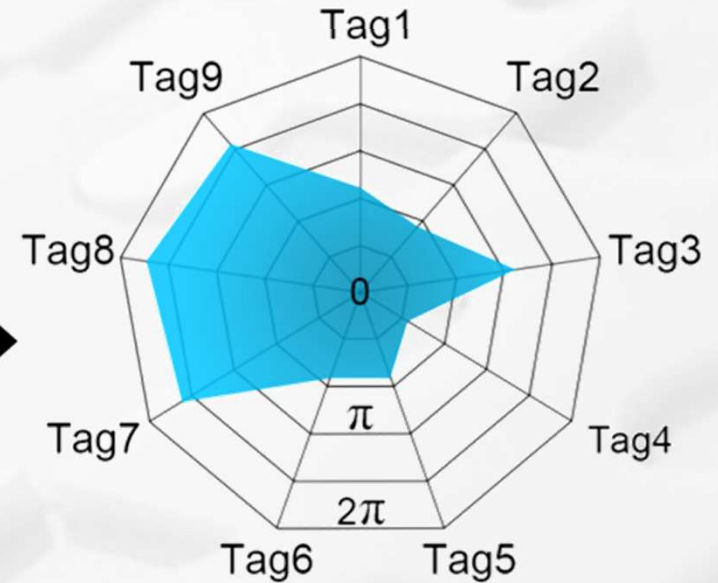
Key Idea



(a) Phase of individual tags



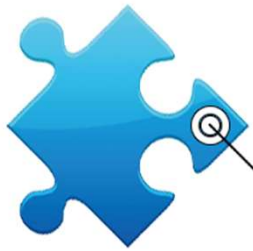
(b) Coupling phase of these tags



**User-dependent & Unique
Phase Fingerprint**

$$\Delta\theta_{ij} = \theta_i - \theta_j = \left(\frac{4\pi d_{ij}}{\lambda} + \Delta\theta_{tag}^{ij} \right) \mod 2\pi$$

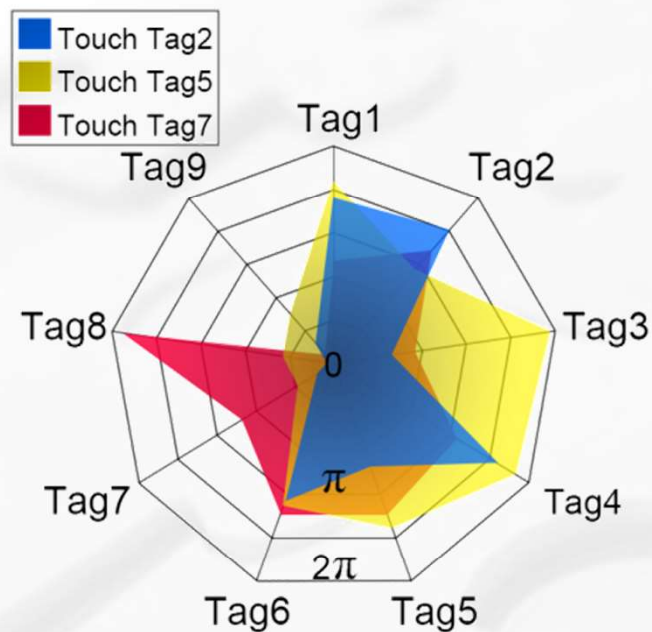
Phase Difference of Tags (PDoT)



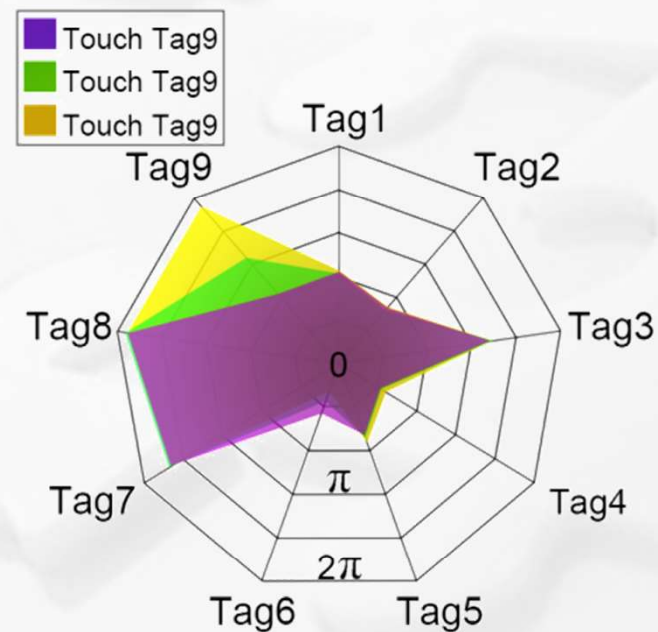
Design

Challenge 1

The impact of touching is unstable.



(b) Touch different tags



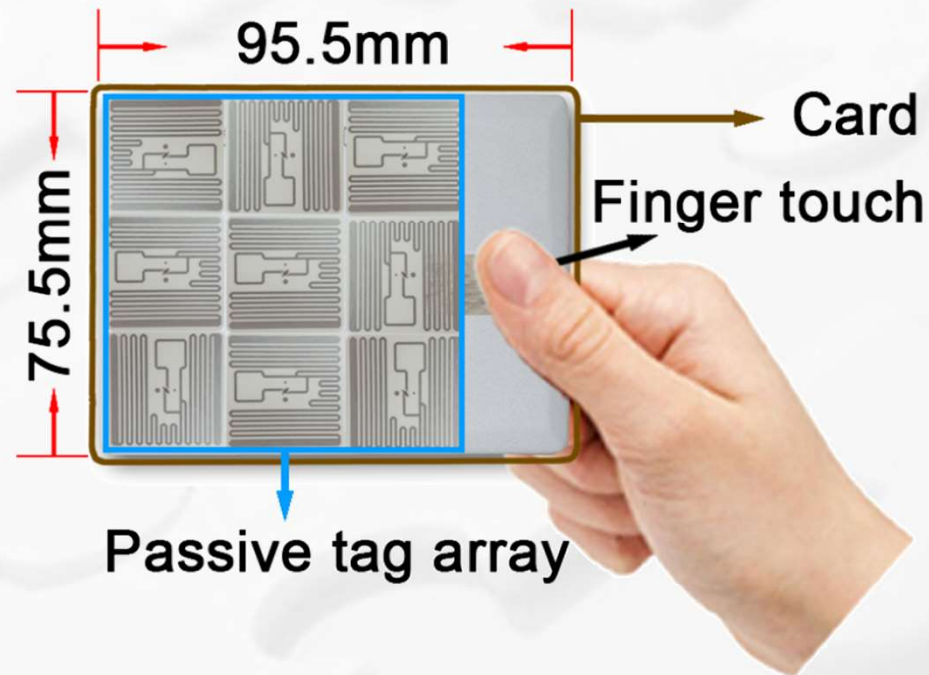
(c) Touch Tag9 three times without conductor



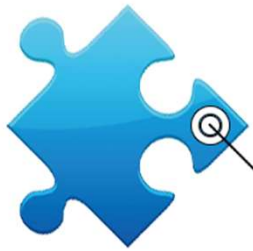
Design

Tackle with challenge 1

Introduce a conductor



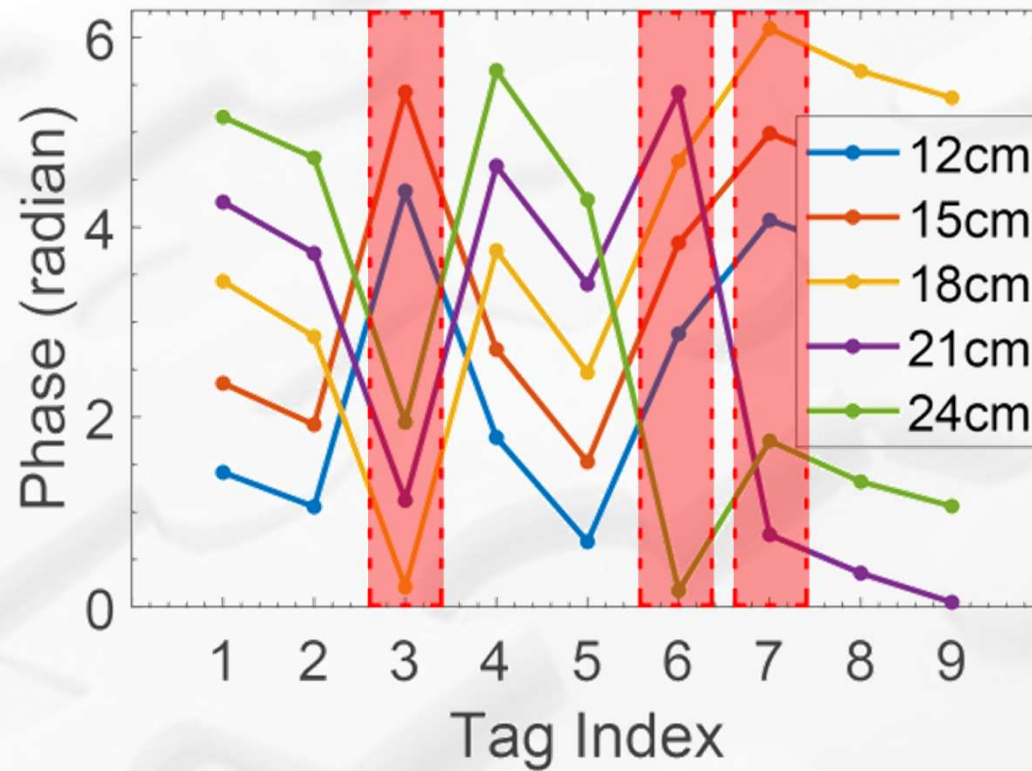
Complexity of **coupling** & **Size** of array

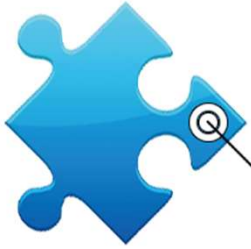


Design

Challenge 2

Phases change with distance.





Design

Tackle with challenge 2

Phase shifting algorithm

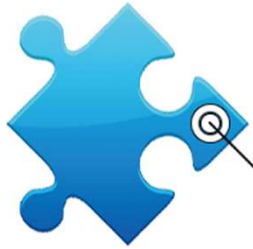
Algorithm 1: Phase Shifting

Input: Unwrapped phase sequence:

$$\theta = (\theta_{t_1}, \theta_{t_2}, \dots, \theta_{t_n}), n \in [1, N]$$

Output: Calibrated phase sequence: $\theta' = (\theta'_{t_1}, \theta'_{t_2}, \dots, \theta'_{t_n})$

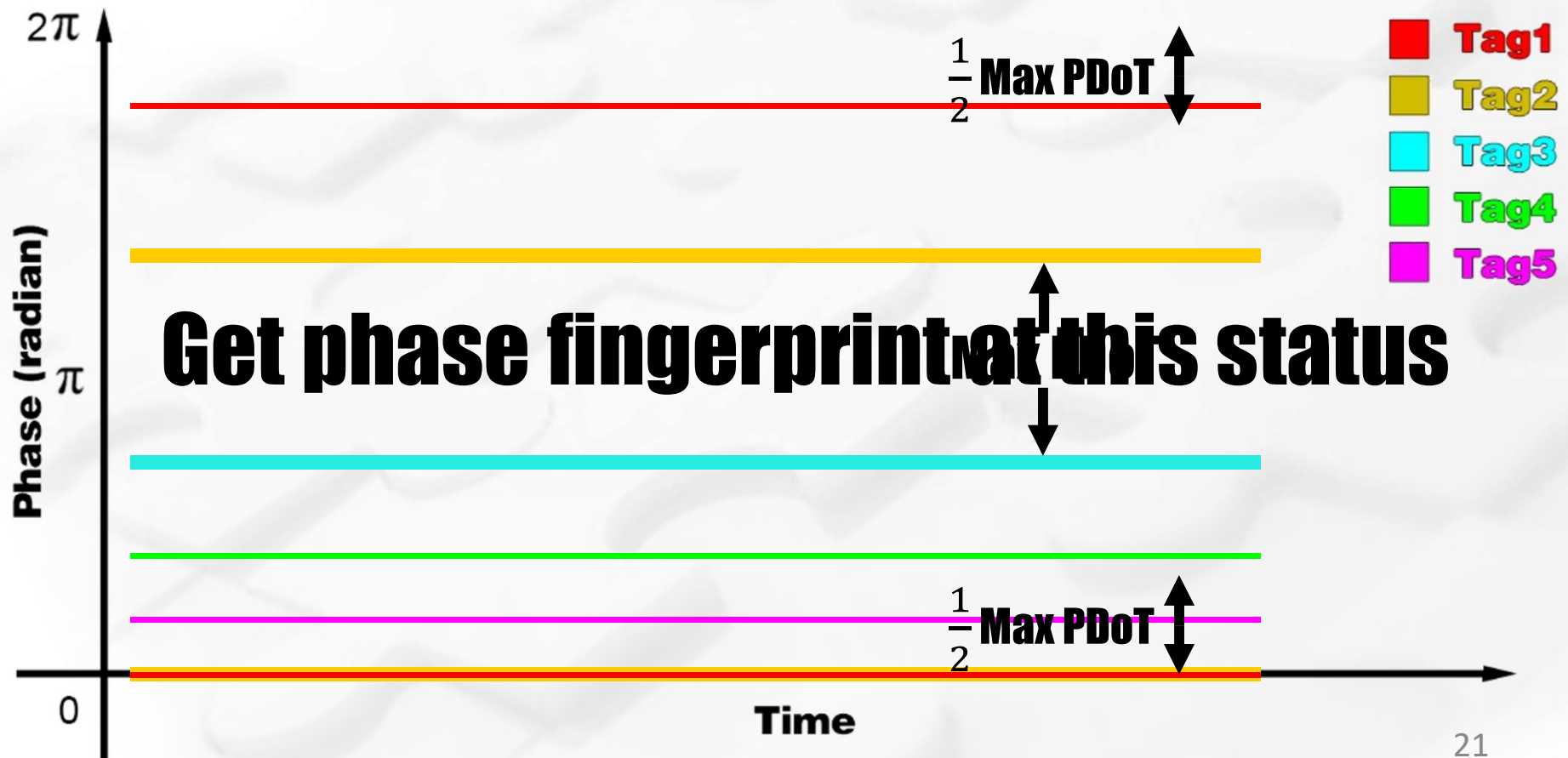
- 1: Descending sort: $\theta \leftarrow \text{sort}(\theta), i \in [1, N]$
 - 2: $i \leftarrow 1$
 - 3: **while** $i < N$ **do**
 - 4: $\delta_i \leftarrow \theta_{t_i} - \theta_{t_{i+1}}$
 - 5: **if** $i == N$ **then**
 - 6: $\delta_i \leftarrow \theta_{t_i} - \theta_{t_1} + 2\pi$
 - 7: **end if**
 - 8: $i \leftarrow i + 1$
 - 9: **end while**
 - 10: Obtain maximum of δ_i : $\delta^{ma} \leftarrow \max(\delta_i), i \in [1, N]$
 - 11: **if** $\delta^{ma} == \delta_N$ **then**
 - 12: $\theta'_{t_i} \leftarrow (\theta_{t_i} - (\theta_{t_N} - \frac{1}{2}\delta^{ma})) \bmod 2\pi$
 - 13: **else if** $\delta^{ma} == \delta_j, j \in [1, N - 1]$ **then**
 - 14: $\theta'_{t_i} \leftarrow (\theta_{t_i} + (2\pi - \theta_{t_{j+1}} - \frac{1}{2}\delta^{ma})) \bmod 2\pi$
 - 15: **end if**
 - 16: Descending sort: $\theta' \leftarrow \text{sort}(\theta'), i \in [1, N]$
-

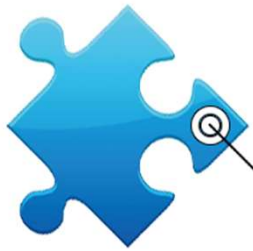


Design

Tackle with challenge 2

Phase shifting algorithm

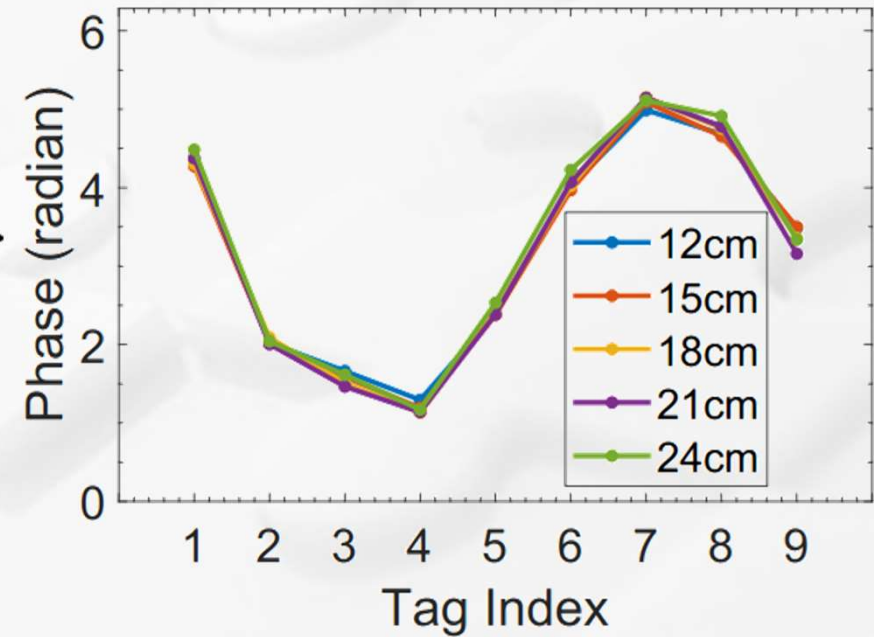
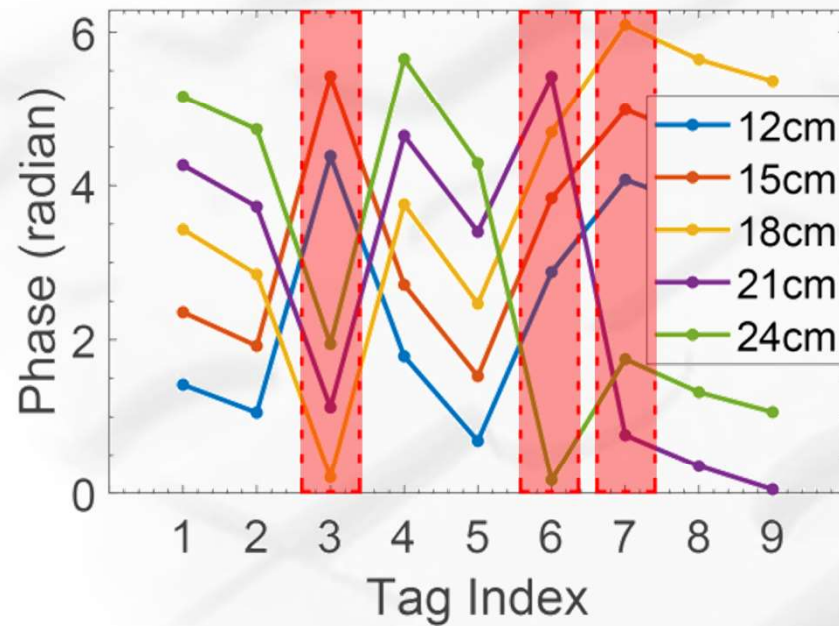


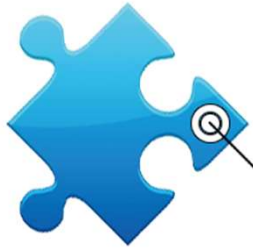


Design

Tackle with challenge 2

Phase shifting algorithm

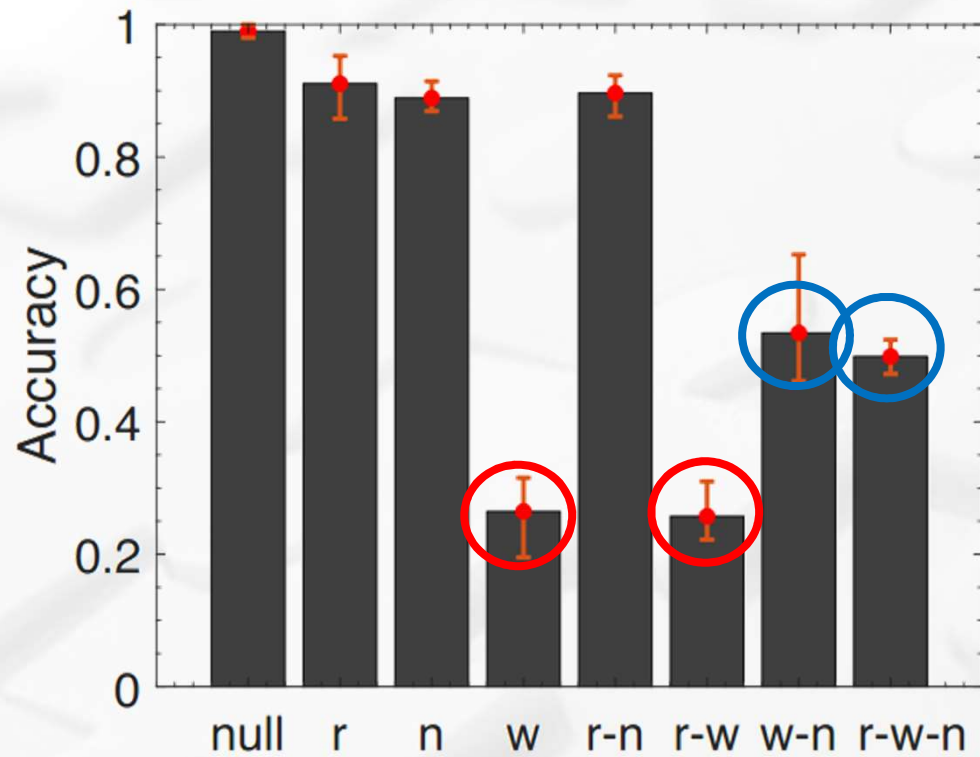




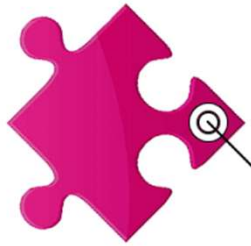
Design

Challenge 3

Impact of accessories



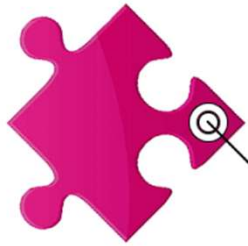
r=ring w=watch n=necklace



Evaluation

1. Impinj R420 reader
2. Laird antenna A9028
3. Alien-9629 tag

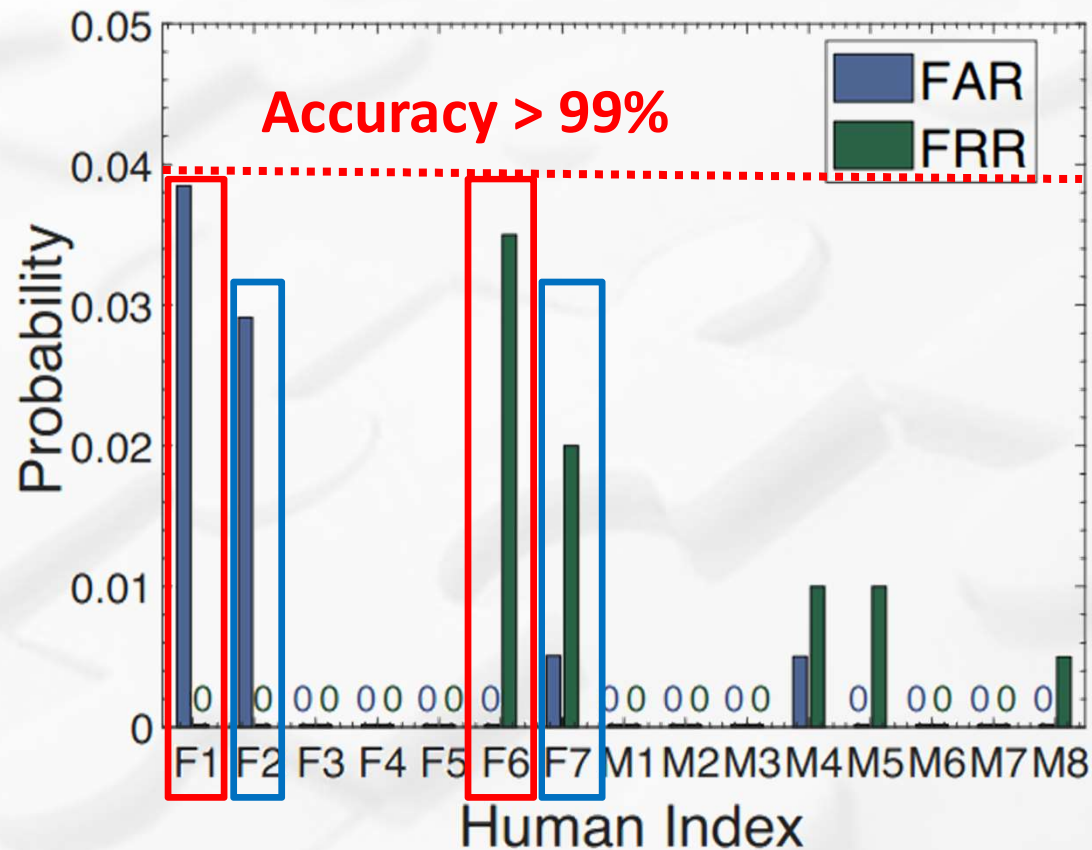


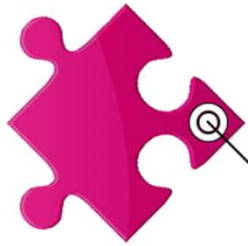


Evaluation

Overall accuracy vs. Human diversity

- 7 females + 8 males
- 15 representative tag array layouts

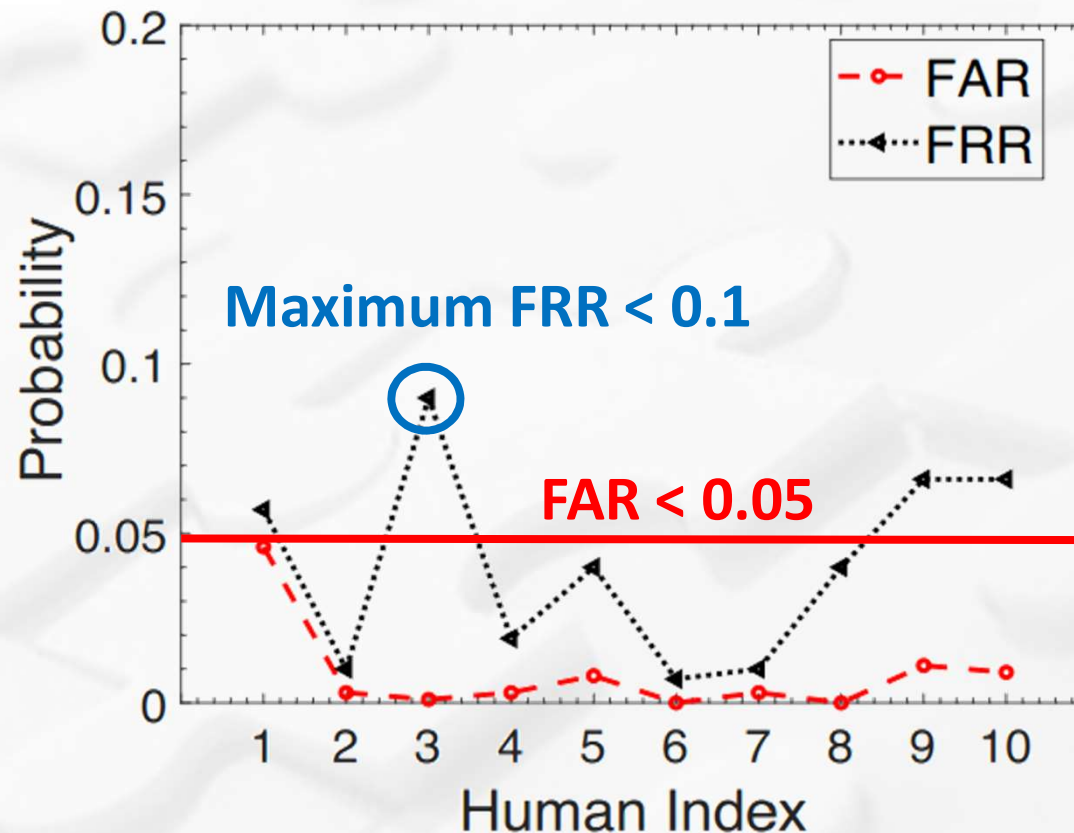


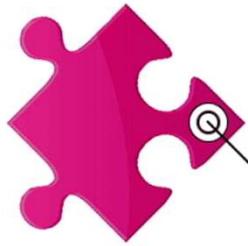


Evaluation

Resisting impersonation attack

- 10 attackers try to use an authorized user's credential to access the system.



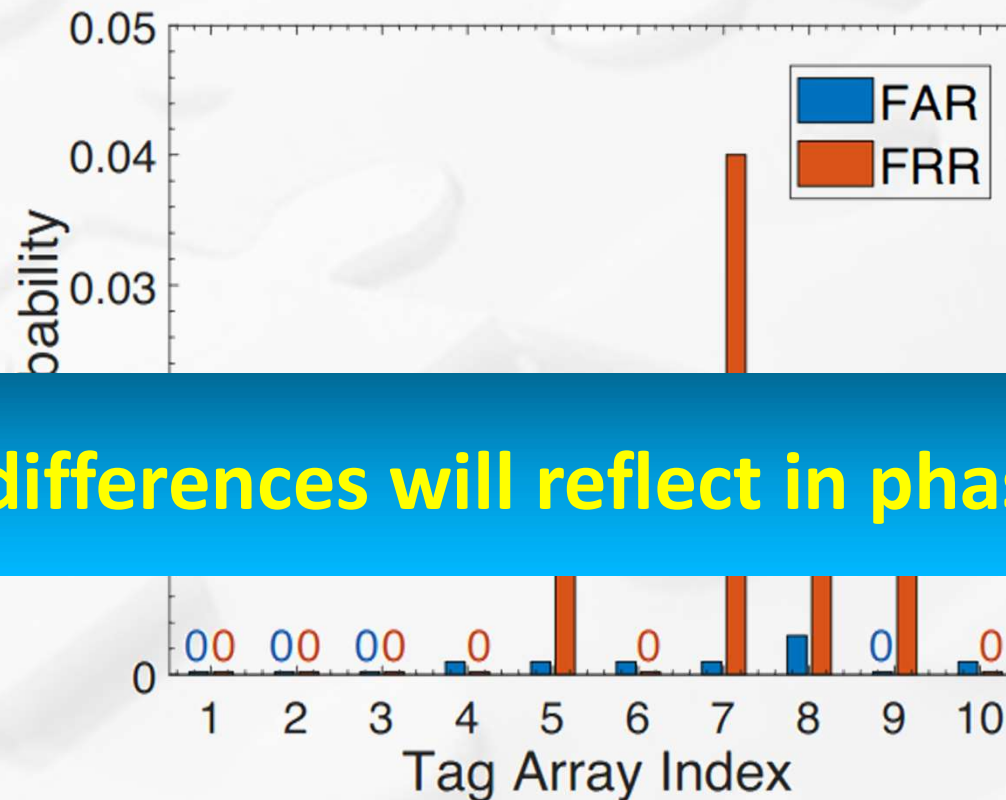


Evaluation

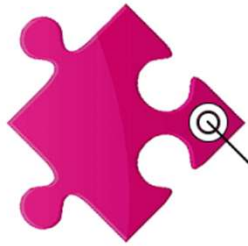
Resisting counterfeiting attack

- Attacker produces a counterfeited array with the same tag model and layout.
 - 90 Alien-9629 tags
 - 10 arrays

Average FAR < 0.01



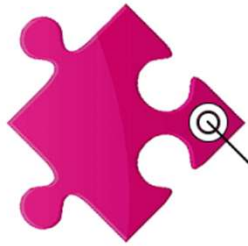
Tags' hardware differences will reflect in phases.



Evaluation

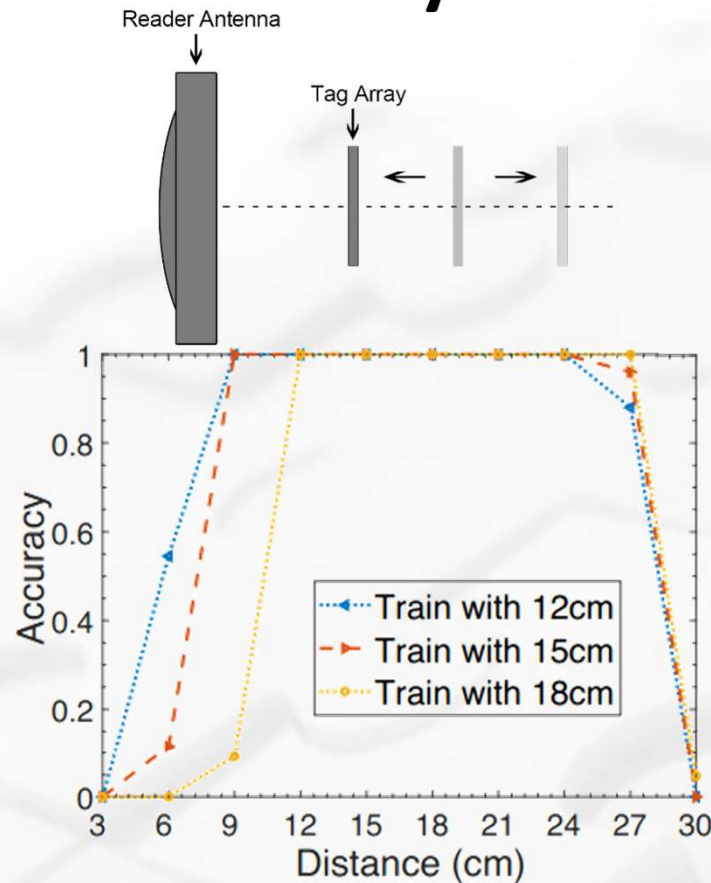
Resisting replay attack

- Effective read range $< 30\text{cm}$
- Tolerable space angle of tag rotation $< 10^\circ$
(w.r.t. x-y-z axis)

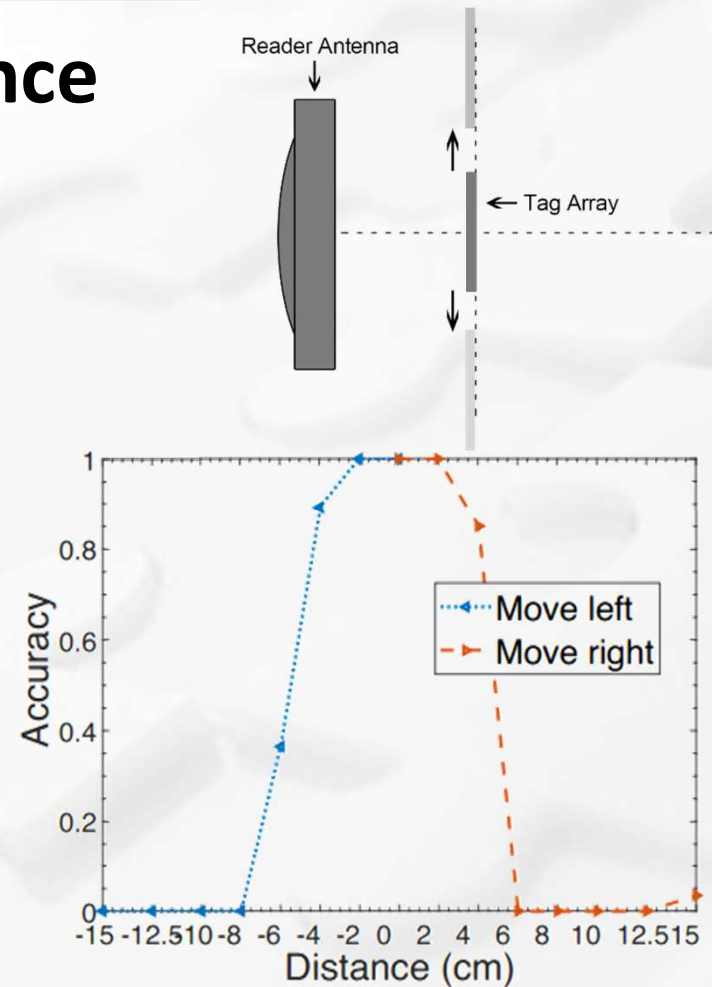


Evaluation

Accuracy vs. distance

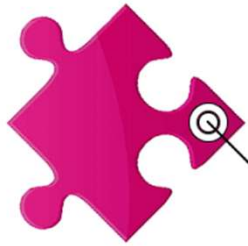


(a) Vertical distance



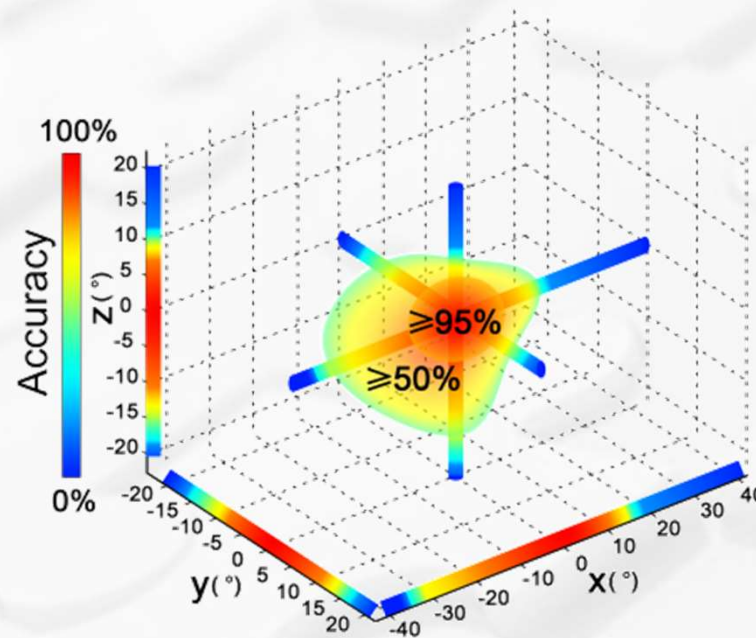
(b) Horizontal distance

Effective authentication range $\approx 15\text{cm}$ $\pm 4\text{cm}$ region $> 90\%$ accuracy

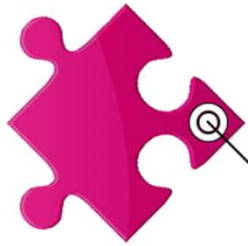


Evaluation

Accuracy vs. rotation and accessories



Tolerable space angle $< 10^\circ$



Conclusion

- Converting **an array of tags** attached on a card into an effective authentication **credential**.
- **Light-weight, low-cost, universal** solution for a **fingertip profiled RF identifier**, authenticating both the card and its holder's identity simultaneously.
- Demonstrated a working system implemented purely based on **COTS RFID devices**.

Thanks! Question?

