RFinder: Pinpoint the Invisible RFID Tags in the Prefabricated Buildings

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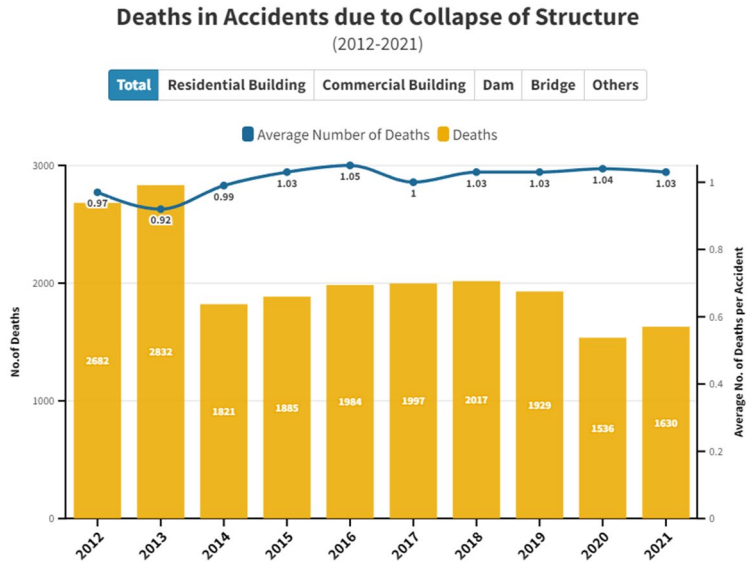
Building Quality Control Is Important

2021 Miami, 98 deaths

Thousands of deaths due to building collapse



Problem: Poorly constructed buildings lead to life-threatening accidents, such as the collapse of buildings and bridges.

Building Quality Control Is Important

2021 Miami, 98 deaths

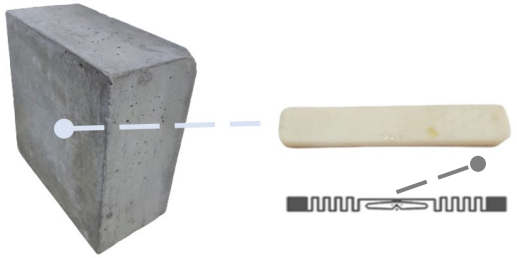
Thousands of deaths due to building collapse

Monitoring structural health of a building is very important !

Problem: Poorly constructed buildings lead to life-threatening accidents, such as the collapse of buildings and bridges.

RFID-based Prefabricated Components

RFID tag in a prefabricated component

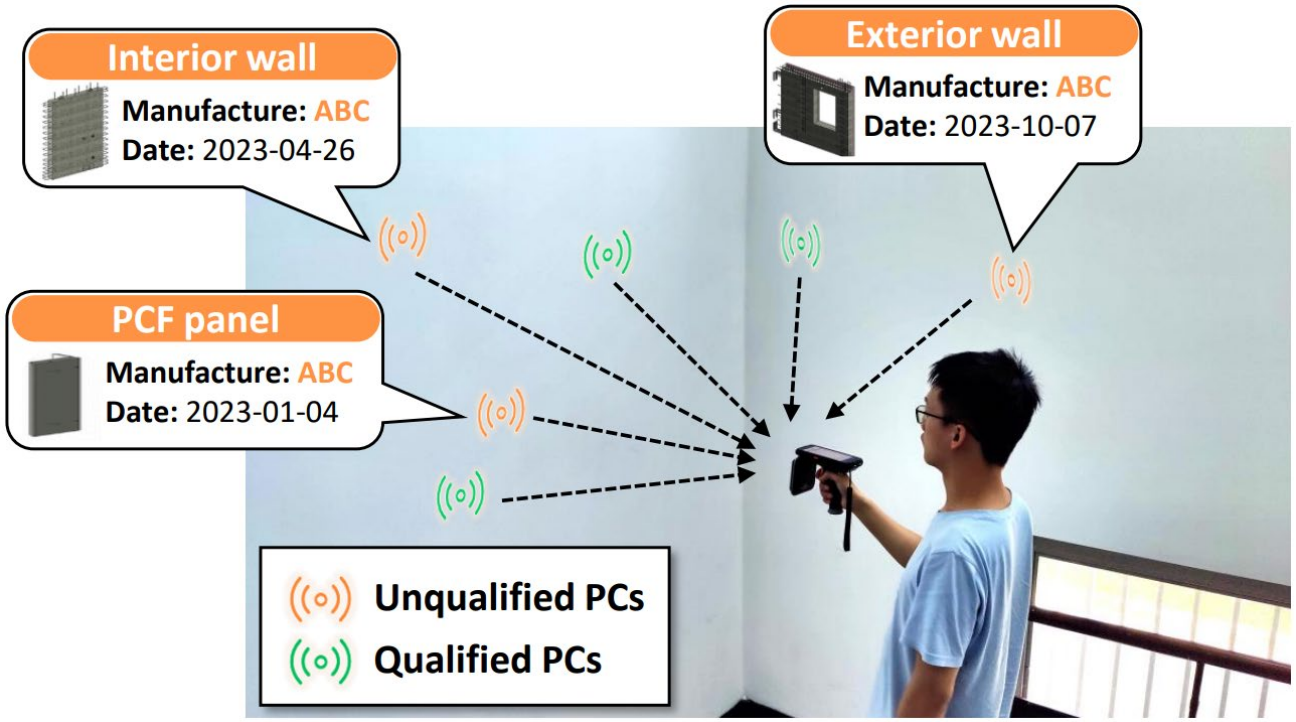


Prefabricated Components management

Different types of commercial prefabricated components with buried RFID tag

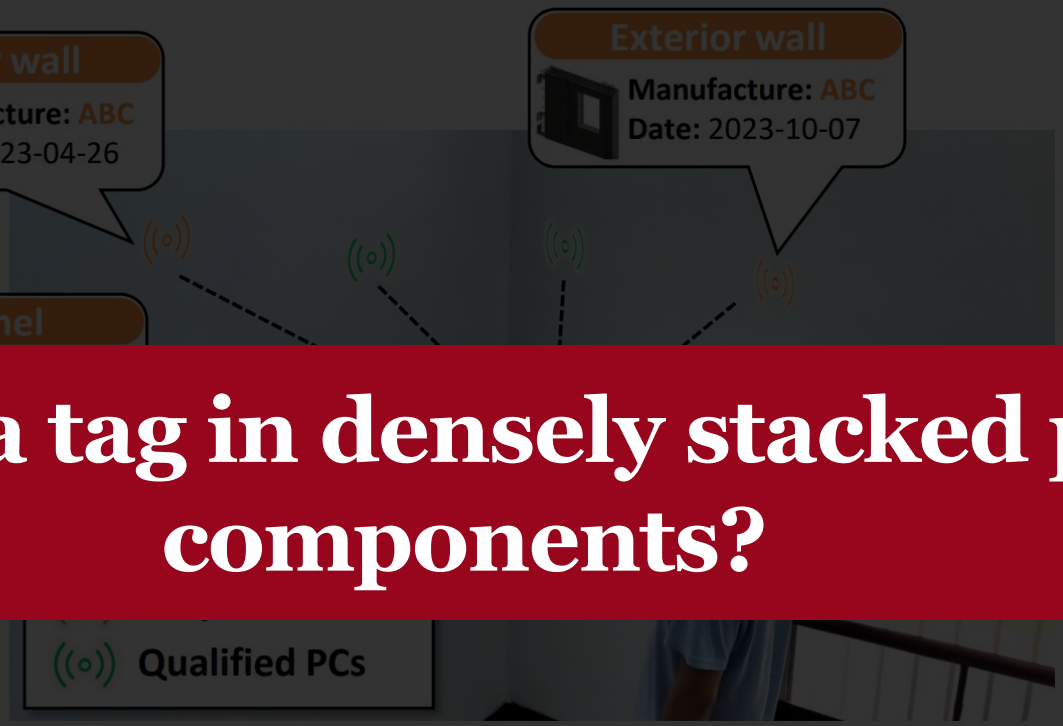
RFID tags can be embedded in prefabricated component (e.g., concrete) to monitor the structural health of the building.

Prefabricated Component Localization



Localizing the RFID tag helps workers to find the location of the prefabricated component, and help them to **trace the source of the component**.

Prefabricated Component Localization



How to localize a tag in densely stacked prefabricated components?

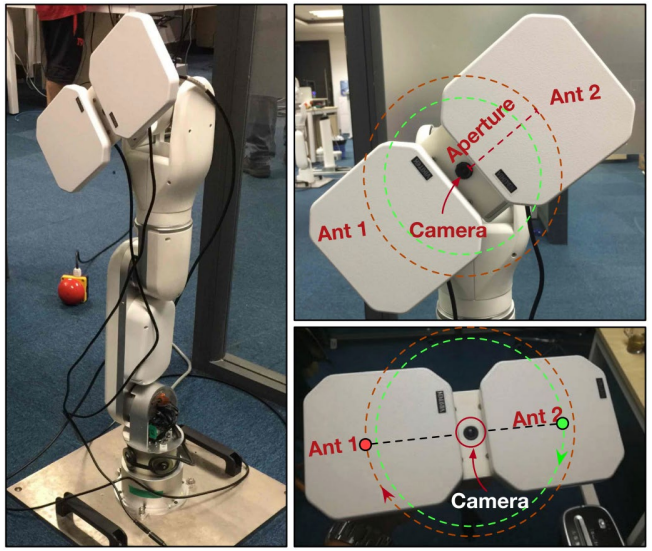
Problem: When querying a tag embedded in a component, all the tags around respond their information. **It's difficult to distinguish these response.**

Existing approaches

Antenna Array

Unavailable on portable devices and not easy convenient for workers to use

Mobile Robots

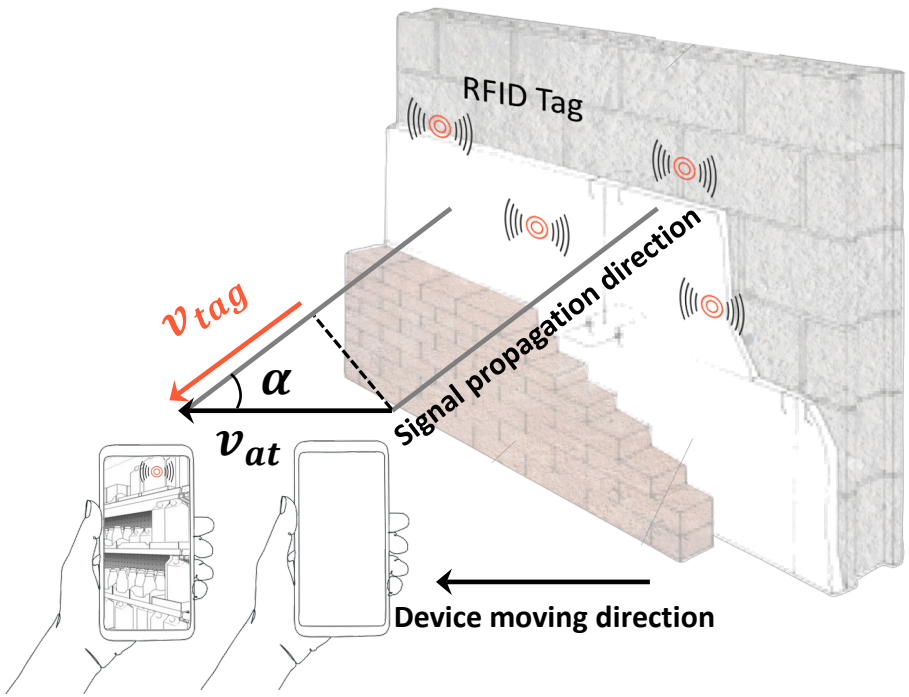


Moving on well-defined trajectories and not suitable for handheld human mobility

Vision + RFID

Not suitable for construction sites where illumination and user motion may change

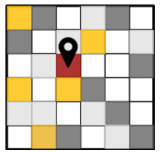
Our Approach



$$v_{tag} = cos(\alpha)\, v_{at}$$

IMU Data
(Acceleration，Angular velocity)

Data Matching



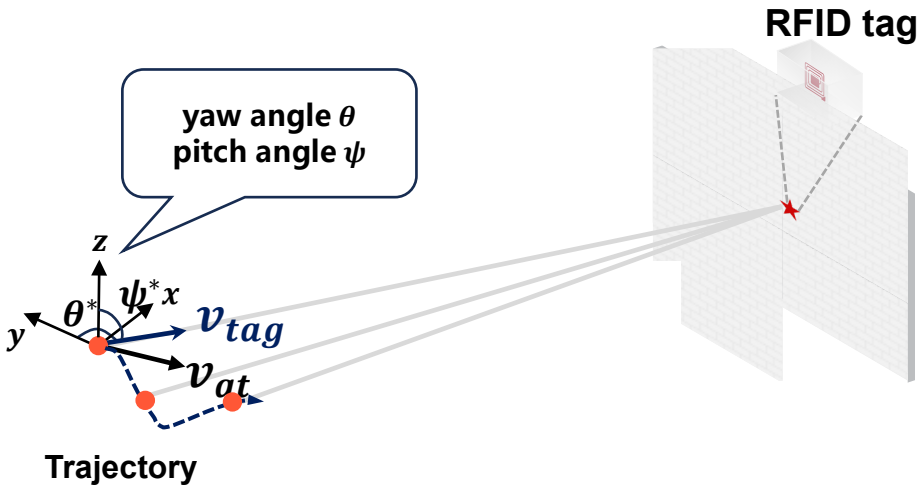
Location Estimation

RFID Signal Phase @900MHz

RFinder combines an IMU data and a COTS RFID reader to estimate the radial velocity v_{at} , and further estimate the AoA α and the location of the tag.

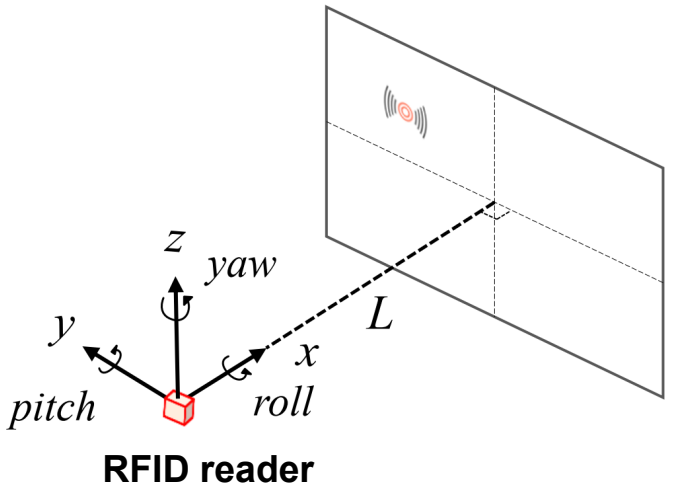
3D AoA Estimation

Searching the AoA of the tag



$$\pi_{tag}(\theta^*, \psi^*) \leftarrow argmin_{\theta,\psi}\left[\sum_{j}^{N}\left(\frac{V_{at,j}\pi_{\theta,\psi}}{||\pi_{\theta,\psi}||} - ||V_{tag,j}||\right)^2\right]$$

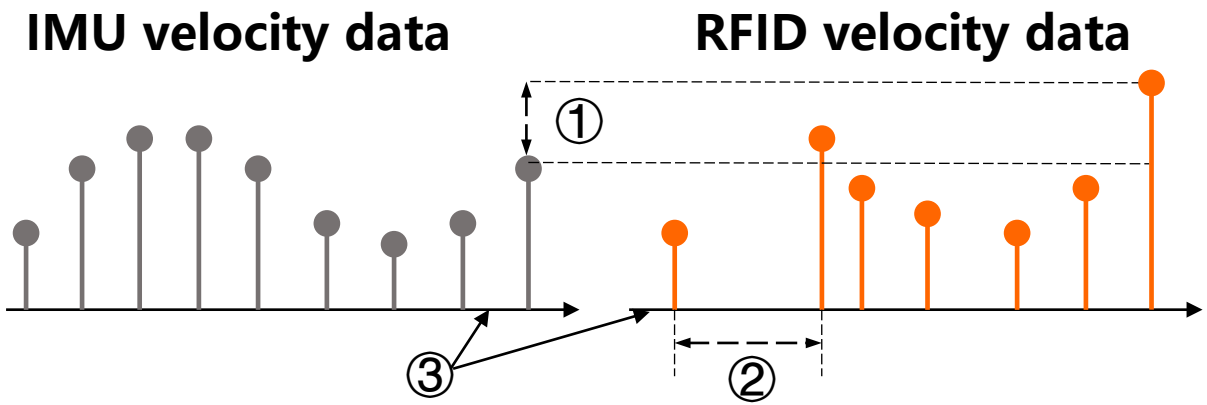
Calculating the location of the tag



$$Loc_{tag}(x, y, z) = \pi_{tag}(x = L)$$
$$= [cos\psi_a cos\theta_a, -sin\theta_a, sin\psi_a cos\theta_a]\frac{L}{cos\psi_a cos\theta_a}$$

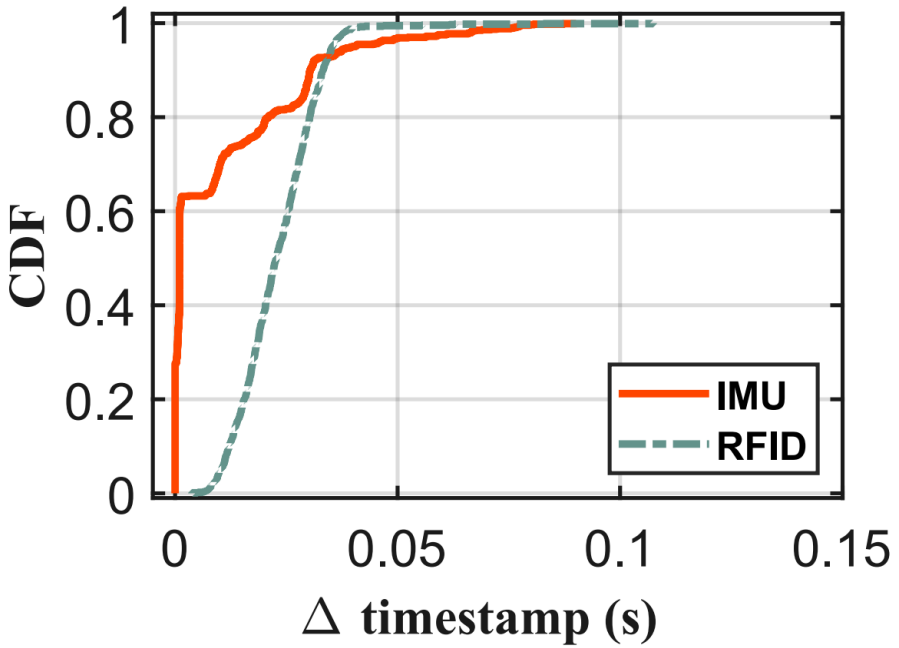
RFinder estimates the yaw and pitch angle to achieve 3D AoA estimation by searching the optimal result of the projection of the radial velocity.

Challenge: How to Match IMU and RFID Data



① **Noise** exists in the velocity data after differentiating RFID phase data.
② **Sampling frequency** of RFID reader is **unstable**, causing **sample loss**.
③ **The clocks** of RFID reader and IMU sensor **are not synchronized**.

Challenge: How to Match IMU and RFID Data

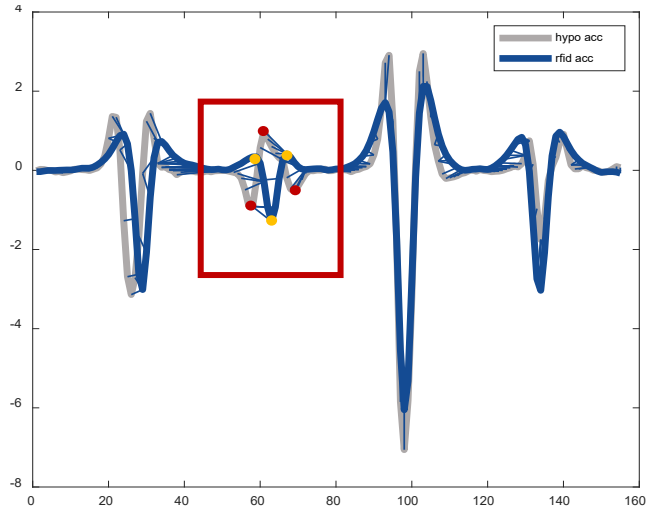


Reading traces of IMU sensor and RFID reader

The **sampling interval** of RFID reader and IMU sensor are quite **different**;
The **sampling rates** of both the two devices are **highly unstable**.

Our solution: TDTW (Time-weighted DTW)

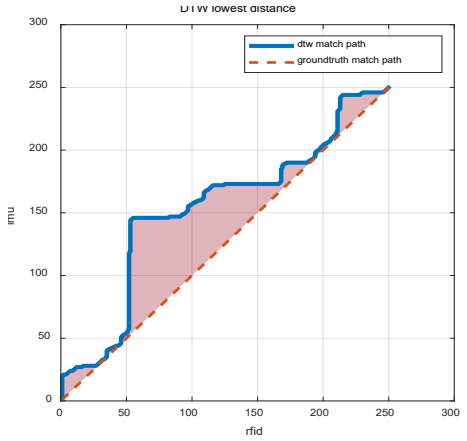
DTW : Time offset still exists



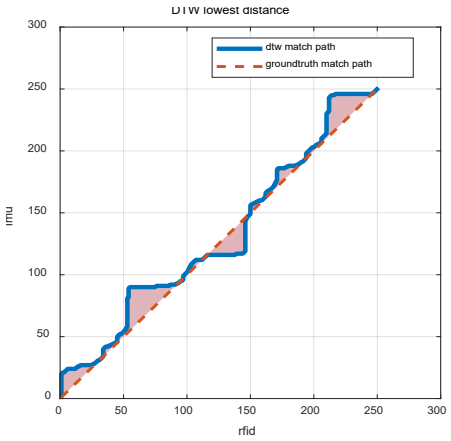
$$D\left(V_a^i, V_b^j\right) = d(i,j) + min\begin{cases} D(V_a^{i-1}, V_b^{j-1}) \\ D(V_a^{i-1}, V_b^j) \\ D(V_a^i, V_b^{j-1}) \end{cases}$$

TDTW : Compensating Time offset

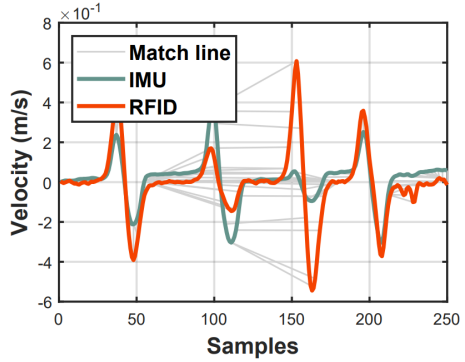
Match path without compensation



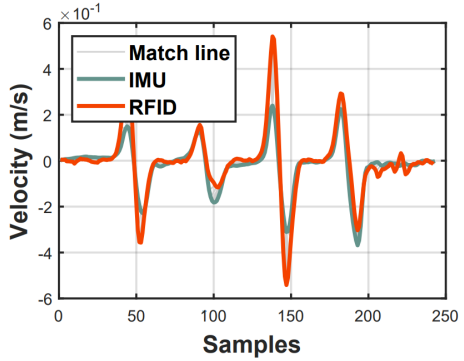
Match path with time compensation



$$D\left(V_a^i, V_b^j\right) = \left|\frac{i-j}{M}\right|^2 + d(i,j) + min\begin{cases} D(V_a^{i-1}, V_b^{j-1}) \\ D(V_a^{i-1}, V_b^j) \\ D(V_a^i, V_b^{j-1}) \end{cases}$$



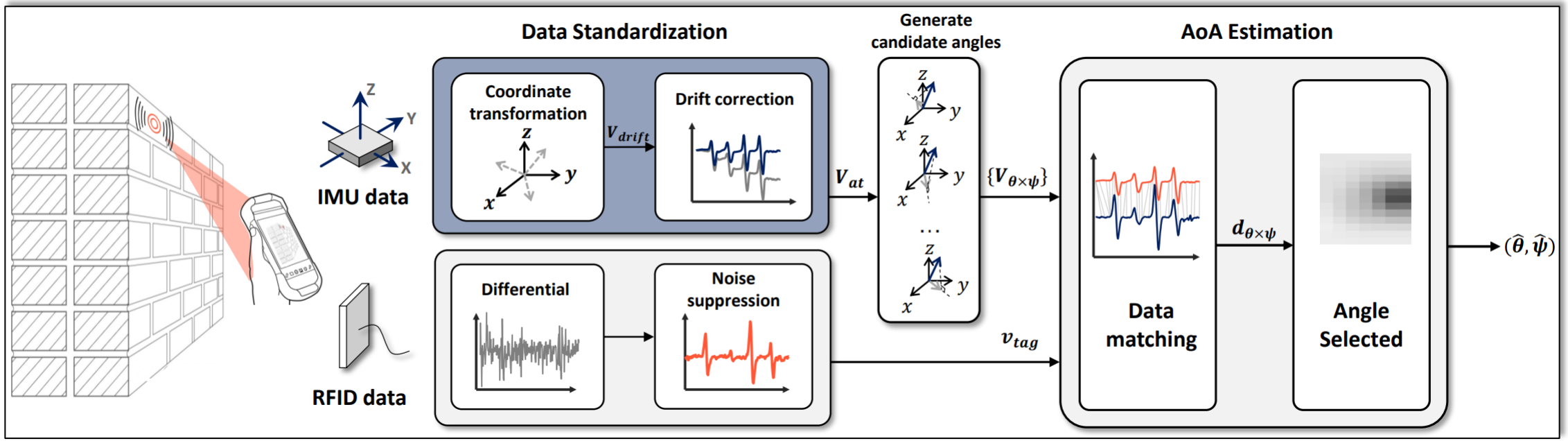
DTW matching result ✗



TDTW matching result ✓

Exploiting **TDTW** can effectively **reduce the wrong match** between the data of IMU sensor and RFID reader.

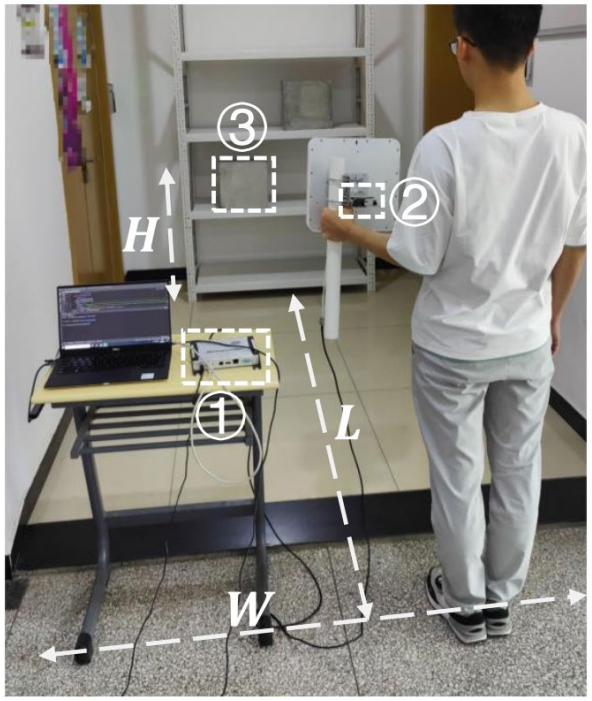
System Overview of RFinder



System overview of RFinder

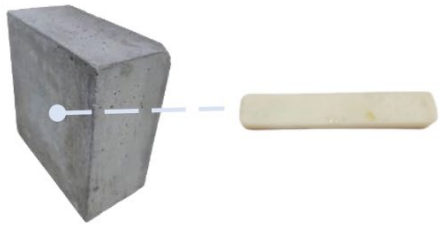
More details please refer to our paper…

Implementation



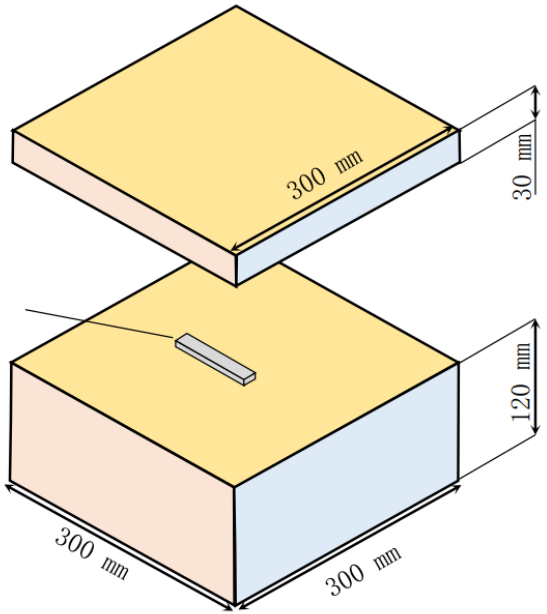
① RFID Reader

② Low-Cost IMU



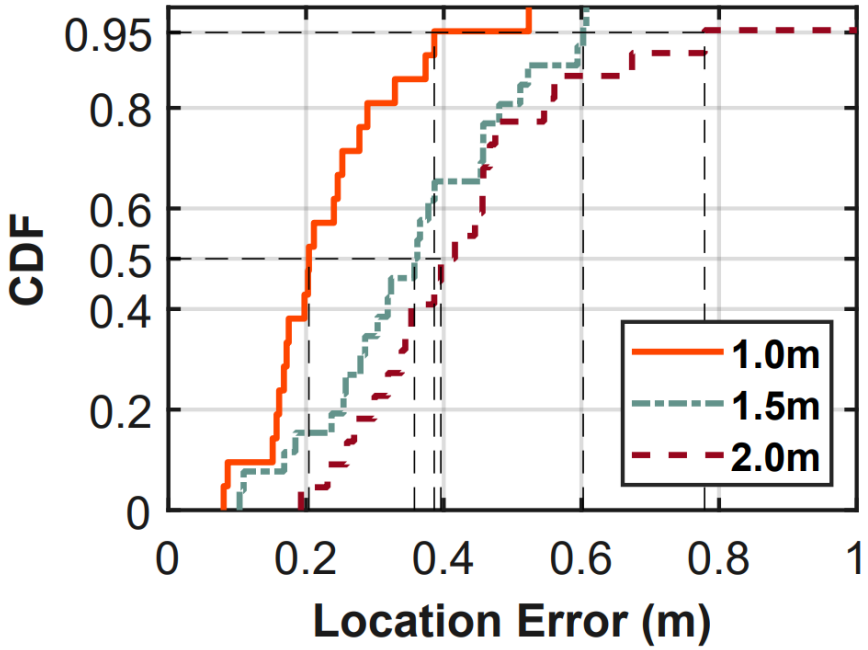
③ The RFID tag is embedded in the concrete component

RFID Tag



① RFID Reader: Impinj R420
② IMU: WHEELTEC N200
③ RFID Tag: Alien H3 9640

Overall Performance

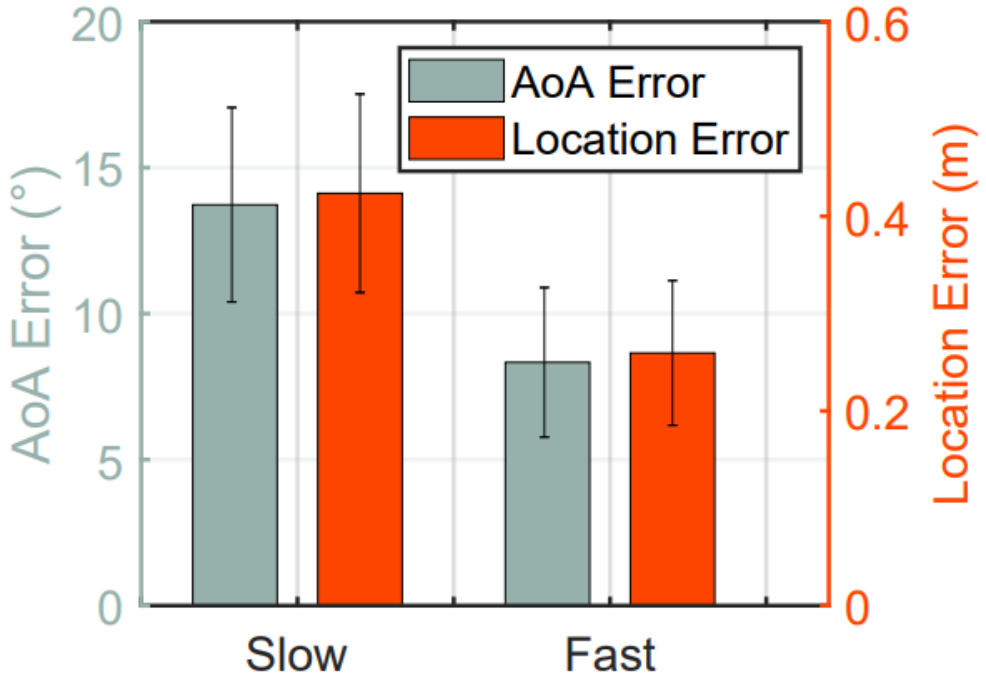


Overall performance in different distance between the tag and the reader

The median location error is **0.2m, 0.36m and 0.40m**, when we set the distance between the tag and the reader at 1m, 1.5m and 2m, respectively.

Impacting Factors

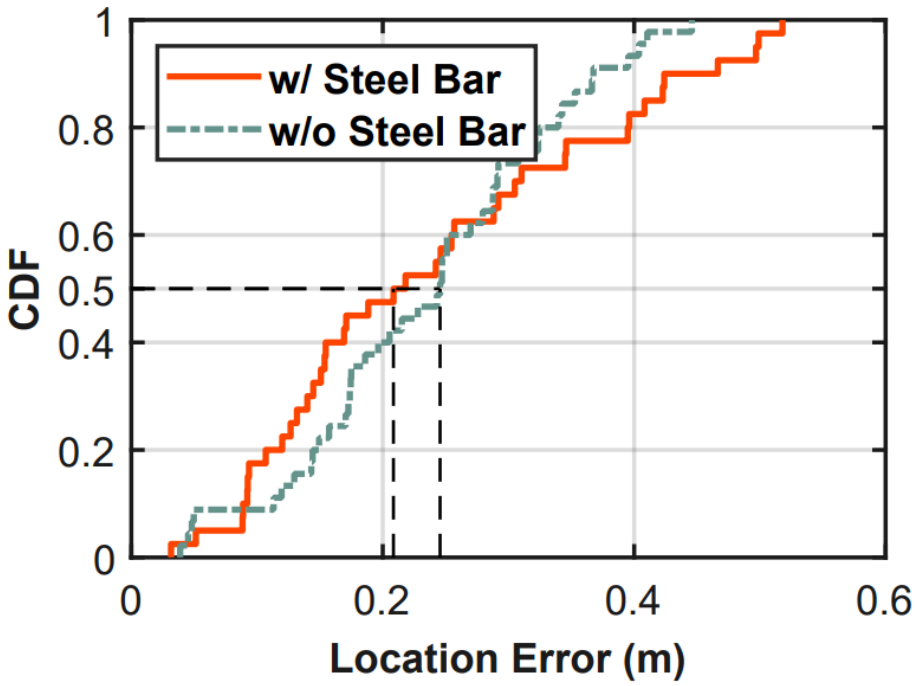
Slow: about 0.25 m/s
Fast: about 0.5 m/s



Impact of the moving speed

RFinder achieves a higher accuracy when the user moves the antenna at a fast speed, because **IMU and phase signals achieve a higher SNR in this case**.

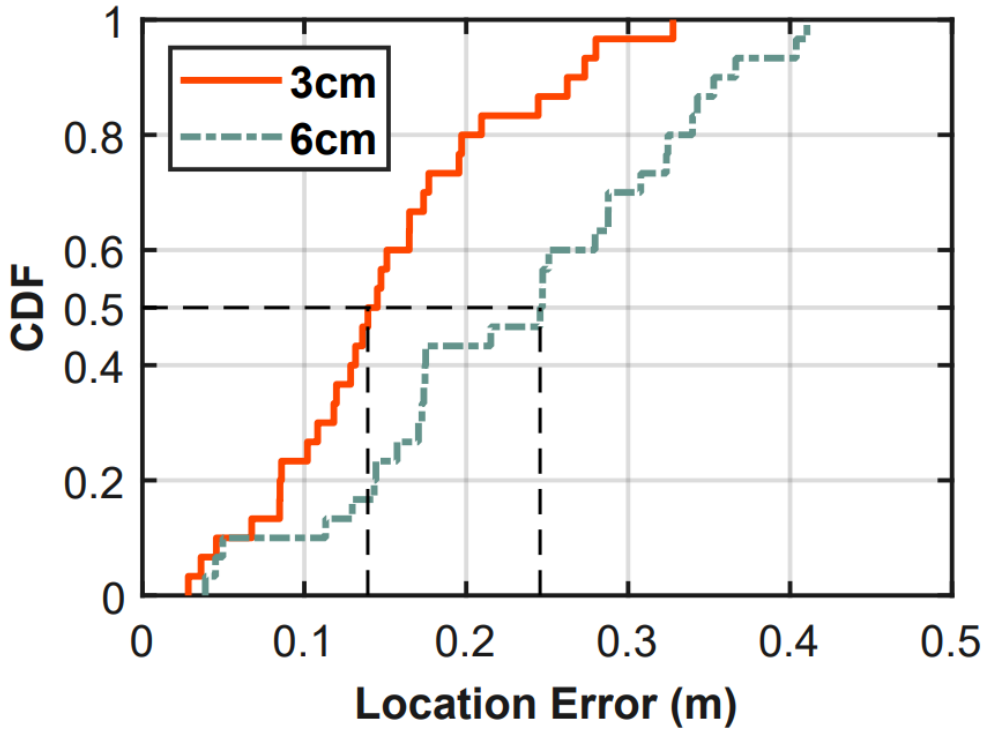
Impacting Factors



Impact of the steel bar in the concrete

The difference between two types of concretes is small, because **signal reflected by the metal is very weak** and can't significantly affect reflected signals of the tag.

Impacting Factors



Impact of the burial depths of RFID tag

The depth where the tag is buried has a impact on the strength of the reflected signal.
Deeper burial depth will lead to higher location error.

Conclusion

- RFinder is **the first portable RFID localization system** that can estimate the AoA of a tag that is embedded in prefabricated buildings.

- RFinder overcomes a series of practical challenges including the drifting in the IMU sensor and the misalignment between IMU data and phase measurement.
- We envision that **RFinder can enable various applications**. For instance, locating misplaced items in retail stores and help medical personnel quickly scan and locate medications.

清華大學 Tsinghua University

Thank You!

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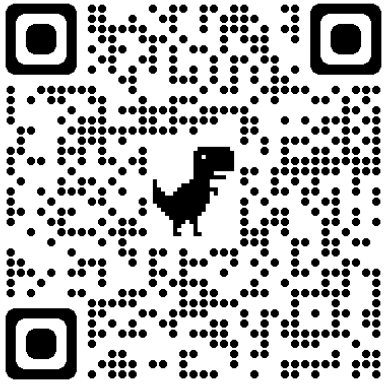
Xin Na, Xiuzhen Guo, **Yuan He***

Please find more details in:



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