WiTrace: Centimeter-Level Passive Gesture Tracking Using WiFi Signals

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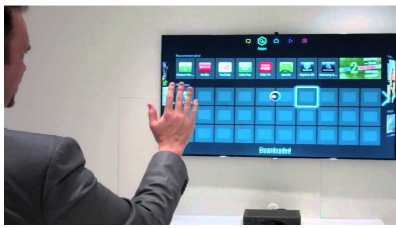
Motivation

- Gesture tracking inspires various applications.


Selecting menu

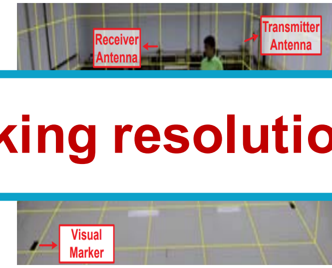

Playing game


AR assistance


VR assistance

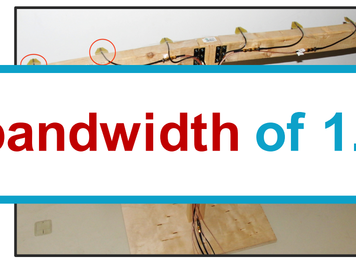
- Tracking with WiFi is superior
  - Ubiquitous: almost everywhere.
  - Non-invasive: not wearing/carrying any devices and protect privacy.
  - Not limited: lighting condition or room layout.

Motivation



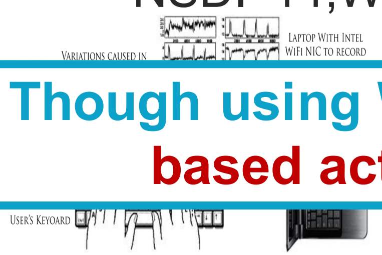
Google project soli | Mobicom'16 LLAP | MobiHoc'17 Widar

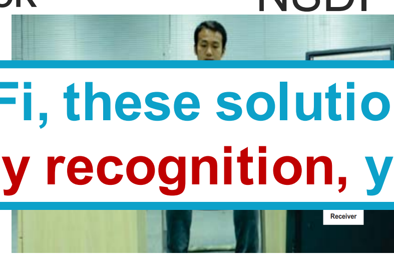
They have either limited range or tracking resolution !

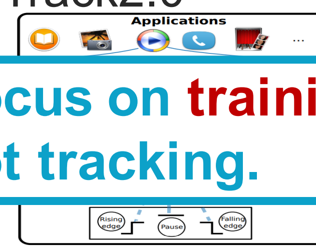


NSDI ’14,WiTrack | NSDI ’15,WiTrack2.0

FMCW signal need a high bandwidth of 1.79 GHz !







Though using Wi-Fi, these solutions focus on training-based activity recognition, yet not tracking.

Mobicom'15 WiKey | UbiComp'16 WiFinger | INFOCOM '15 WiGest

Problem Statement

- Can we build a gesture tracking system:
  - Using WiFi signals?
  - With high precision
  - With large working range

CSI Phase Model

- Challenge-1:
  - What characteristics of WiFi can be leveraged to achieve cm-level tracking precision?
- Solution:
  - CSI phase
- Advantage:
  - CSI provides more information than other WiFi characteristics (RSSI).
  - CSI Phase has higher precision over CSI amplitude.

CSI Phase Model

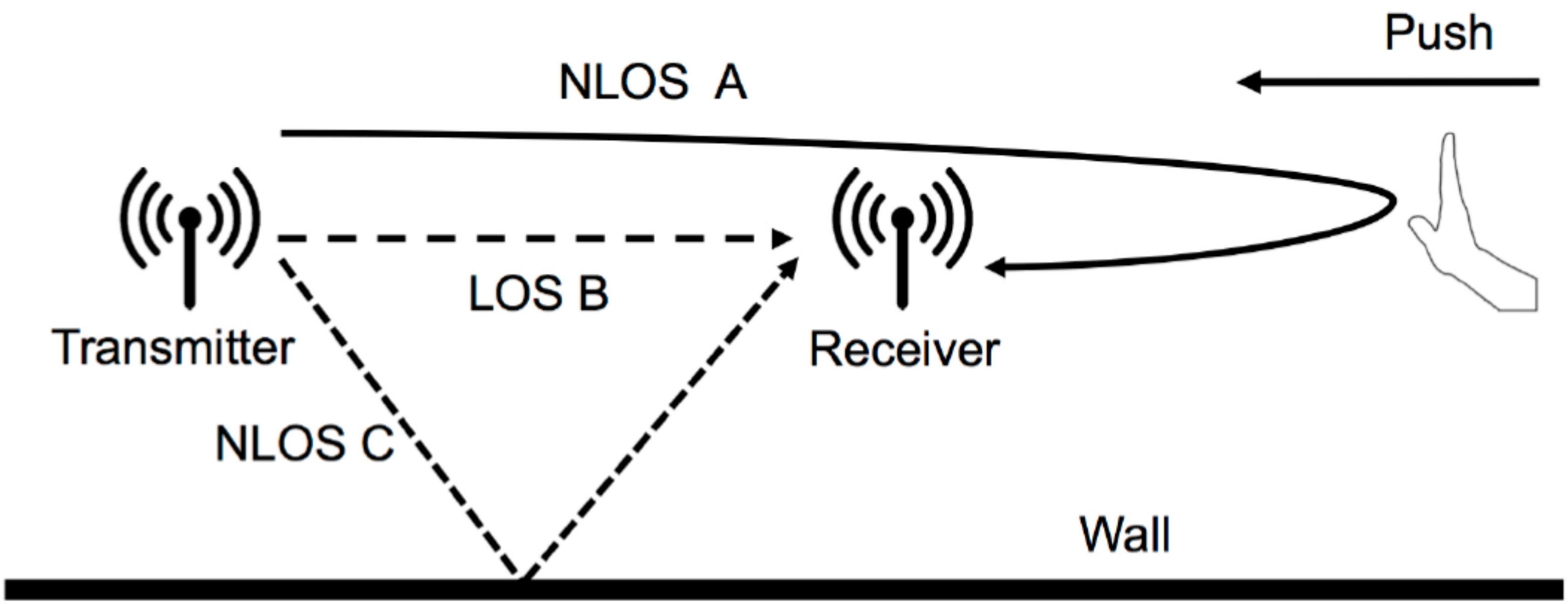
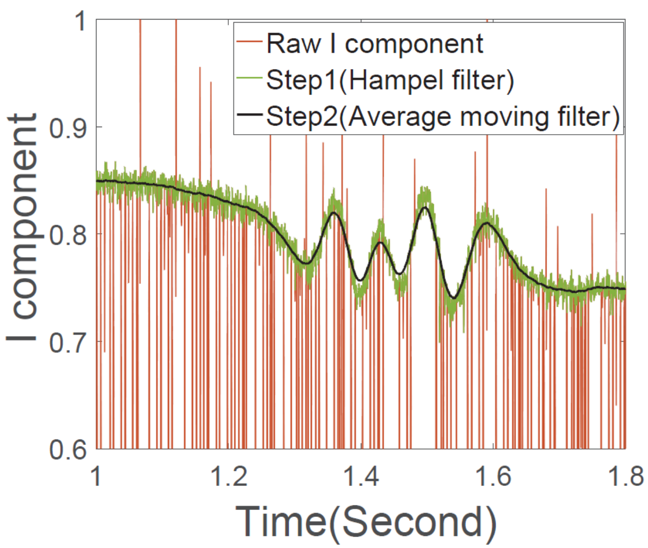
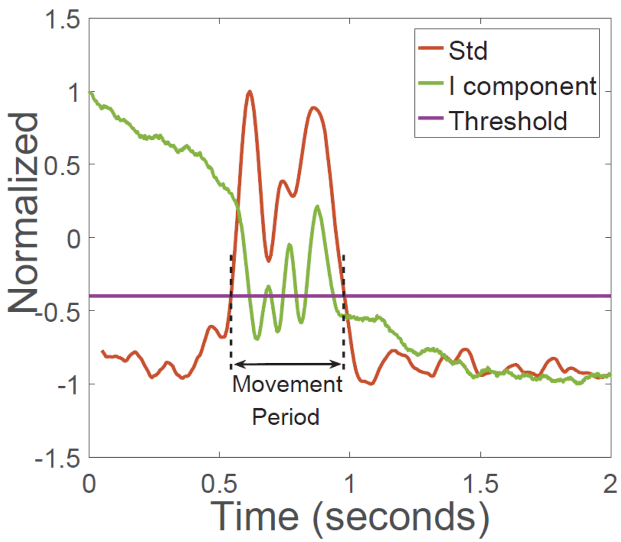


Illustration of multiple paths

1-D Tracking

- Denoise the CSI signal
  - Hampel filter
  - Average moving filter
- Detect the movement





1-D Tracking

- Challenge-2:

  How to seperate the phase changes caused by moving hands from CSI values due to other environments?

- Existing work:

  DDBR: low surrounding noise and can hardly detect slow movement.

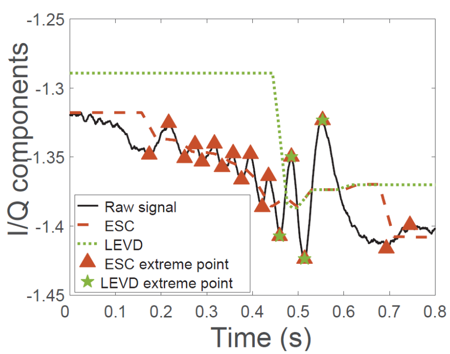
  LEVD: difficult to reliably detect the local maximum and minimum points

1-D Tracking

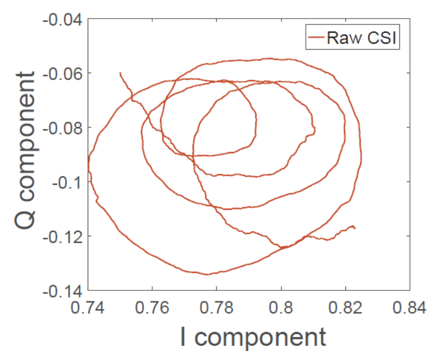
- Extracting Static Component (ESC):
  - Find alternate maximum and minimum points that are lzrger than the emperical threshold.
  - STFT to derive the instaneous Doppler frequency shift.
  - Remove extreme points smaller than threshold.
  - Average adjacent two points to derive the static value.

1-D Tracking

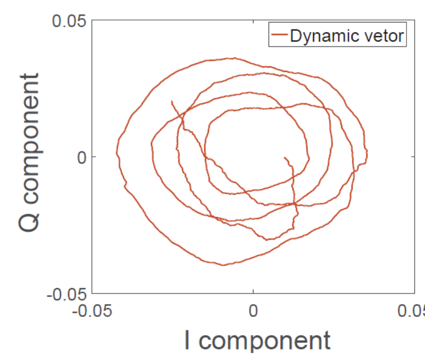
- ESC vs. LEVD:
  - ESC improves the robustness to small ambinent noise than LEVD
  - ESC is more sensitive to small body movement than LEVD



ESC vs LEVD



I/Q trace of raw CSI



I/Q trace of dynamic vector

2-D Tracking

- Challenge-3:

  How to estimate the initial position of hand in 2-D space?

- Existing work:

  mTrack: discrete beam scanning mechanism to pinpoint the object's initial localization.

  LLAP: IDFT to process CFR signals for all subcarriers to estimate the absolute position.

- Basic idea:

  Two preamble gestures to measure the initial position of hand.

2-D Tracking

- Initial Position Estimation
  - User push hand along x-axis and y-axis;
  - Set the grid (x_i, y_i) as the candidate initial position;
  - Calculate the tracking trajectory (x_i', y_i') for two receivers based on the initial position and path change for two directions.

2-D Tracking

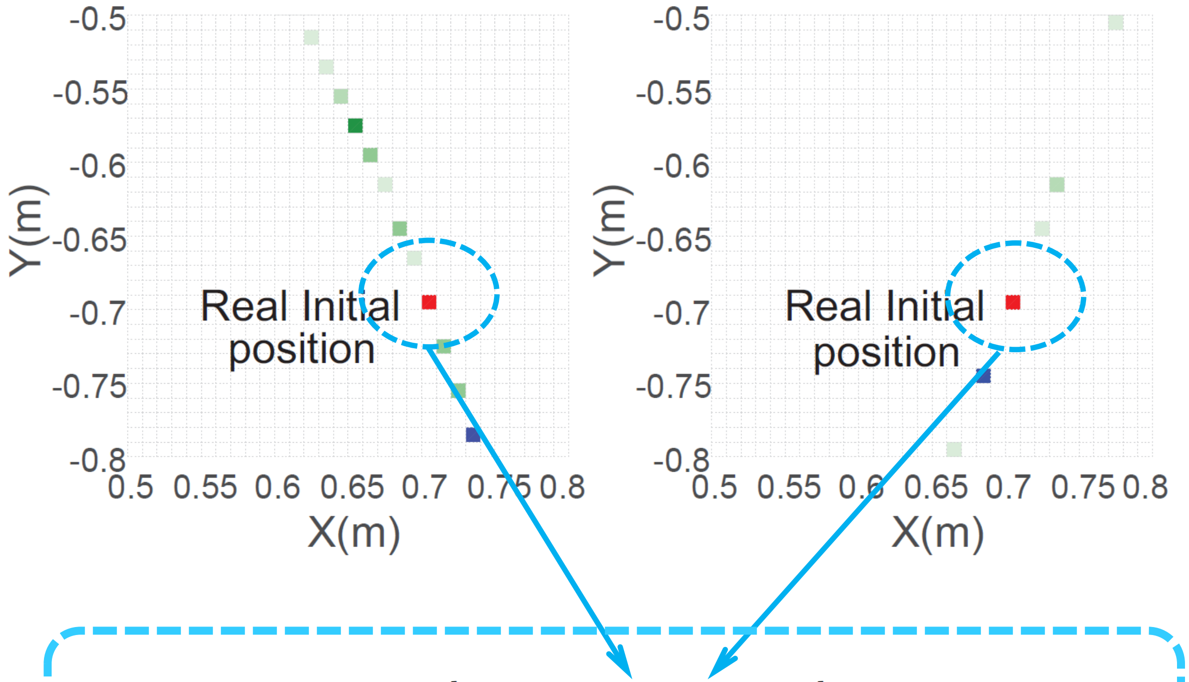
- Initial Position Estimation
  - Find N candidate positions (x_i, y_i) which have the N top smallest deviations $|\hat{x}_i - x_i|$ and $|\hat{y}_i - y_i|$ for x-axis and y-axis, respectively.
  - Calculate N*N distance matrix Z, where

$$Z_{i,j} = \sqrt{(x_i^h - x_j^v)^2 + (y_i^h - y_j^v)^2}$$

  - Find the smallest element in the matrix and average the coordinate value.

2-D Tracking

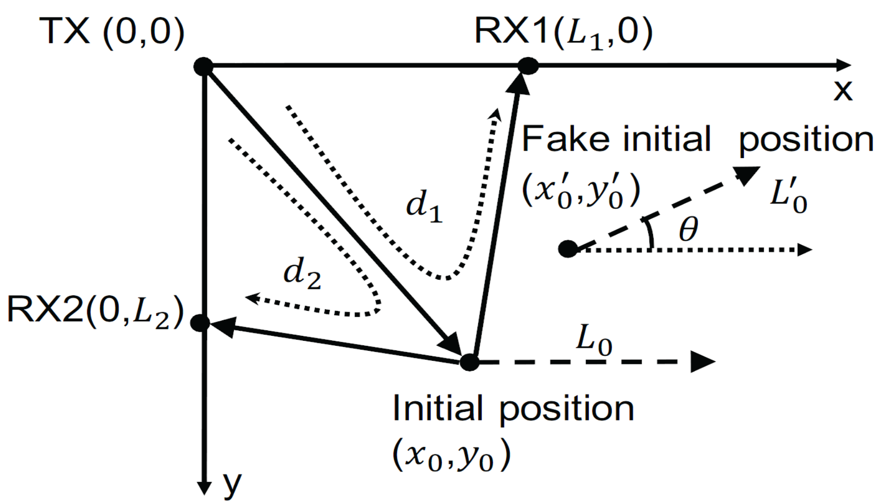
- Initial Position Estimation



$$(x_0, y_0) \leftarrow \left(\frac{(x^h_{i_{min}} + x^v_{j_{min}})}{2}, \frac{(y^h_{i_{min}} + y^v_{j_{min}})}{2}\right)$$

2-D Tracking

- Successive 2-D tracking
  - Estimate the initial hand position
  - Solve two equations corresponding to two receivers

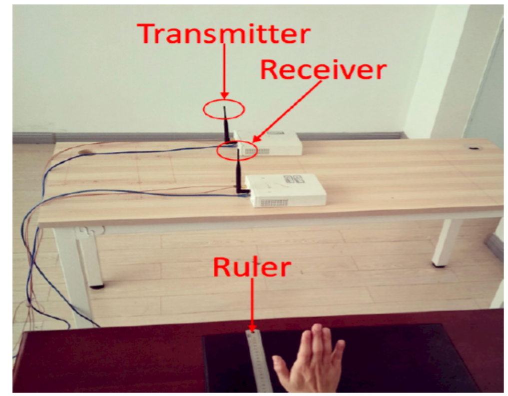


- Trajectory Correction
  - Kalman filter based on CWPA model

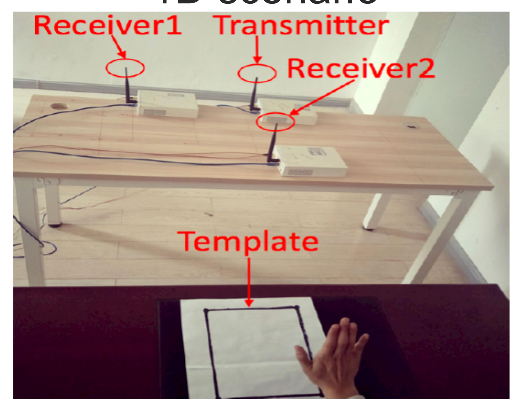
Implementation

- Devices
  - 3 USRP-N210
  - 2 links (1 per receiver)

- Parameters:
  - 20 MHz bandwith
  - 64 CSI subcarriers
  - Central frequency at 2.4GHz
  - Tx power: 20dBm



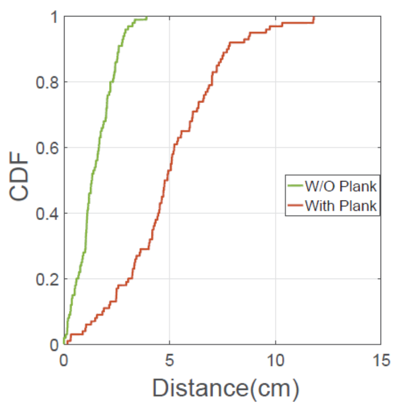
1D scenario

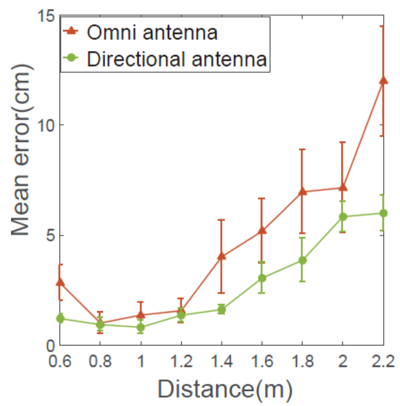


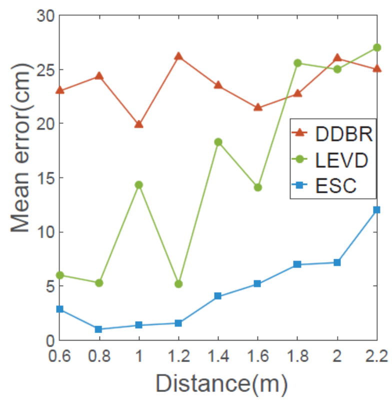
2D scenario

Experiment

- **1-D tracking performance**
  - WiTrace achieves average error of 1.46 cm and 4.99 cm with and without the plank.
  - WiTrace achieves average error of 3.75 cm and 2.51 cm for omnidirectional antenna and directional antenna.
  - ESC achieves better performance than other algorithms.

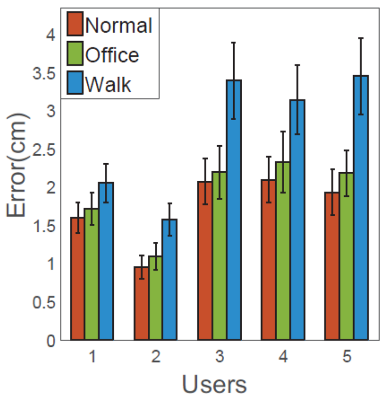


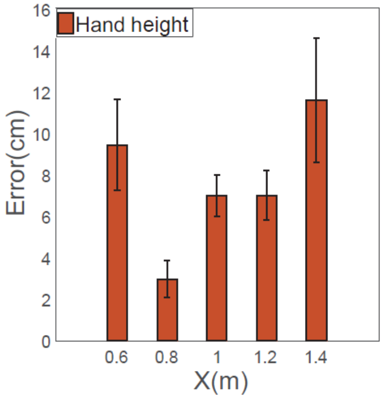


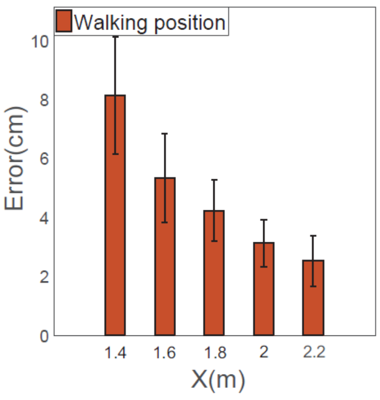


Experiment

- 1-D tracking performance
  - WiTrace is robust to background activities which are 2 m away from the receiver for different users.
  - WiTrace achieves average tracking error of 6.46 cm and 3.80 cm while pushing hand at different heights and walking around, respectively.

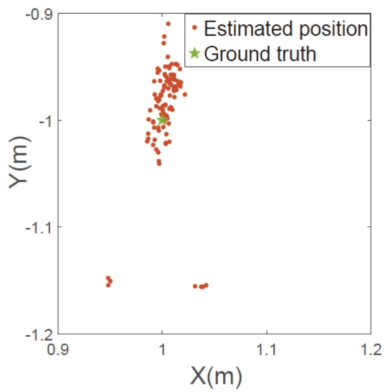


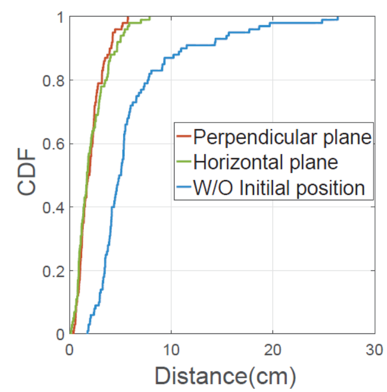




Experiment

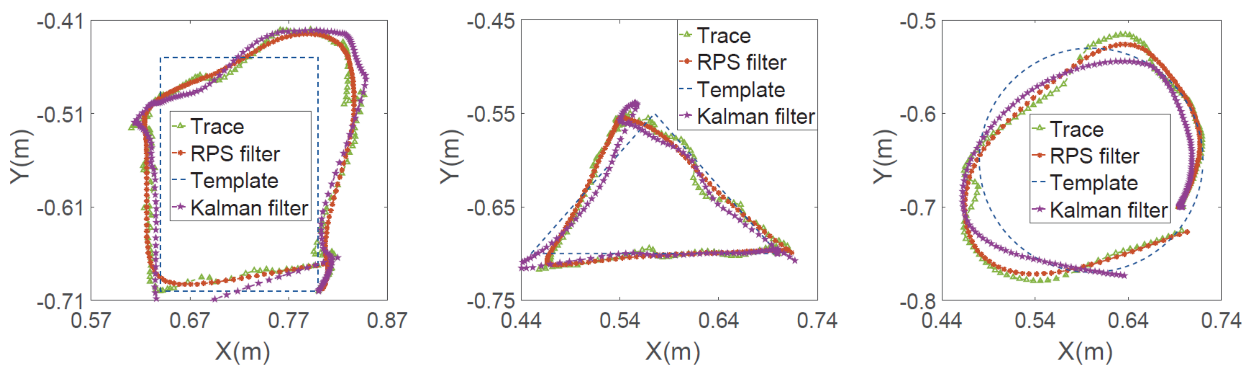
- 2-D tracking performance
  - WiTrace achieves average 3.91 cm estimated error with the template,and average 10.18 cm error without template for intial position estimation.





Experiment

- 2-D tracking performance
  - WiTrace achieves an average tracking error of 2.09 cm for three shapes' trajectory (i.e., rectangle, triangle, and circle).



Conclusions

- WiTrace achieves high accuracy gesture tracking using WiFi signals.
- We propose a novel scheme based on two preamble gestures to measure the initial position of hand.
- We implement WiTrace on USRP.

Q&A