Wi-Run: Multi-Runner Step Estimation Using Commodity Wi-Fi

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2018.06

Outline

1 Motivation

□ Necessity of quantifying amount of warm up exercise

■ Amount: motion, physical injuries and so on

□ Steps are fundamental unit of human locomotion

■ A preferred metric for quantifying physical activity

□ Medical rehabilitation

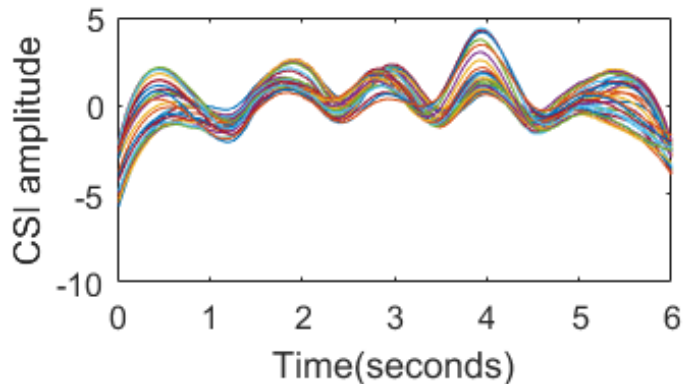■ Amount, motion posture

□ Entertainment and fitness

1 Challenge

☐ Ordinary time-frequency analysis methods, such as FFT or STFT, do not work

- ■ The loss of time domain information
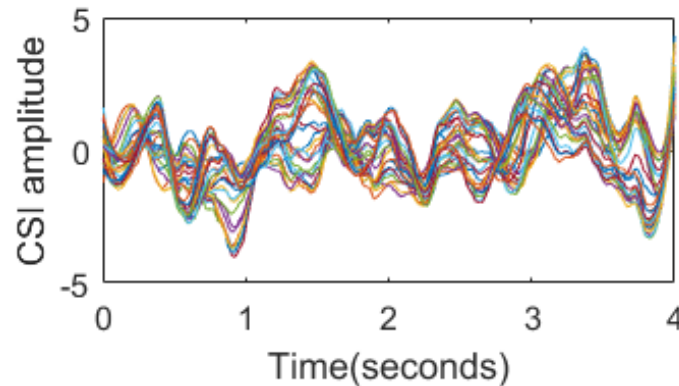
  - Sliced into pieces

- ■ So similar that they can be overlapped
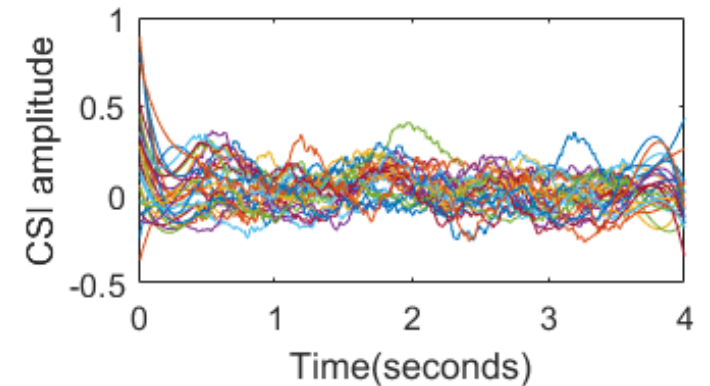
  - Multiple independent movements simultaneously

(a) Single runner CSI dynamics   (b) Three runners CSI dynamics   (c) CSI dynamics without human

2 Solution

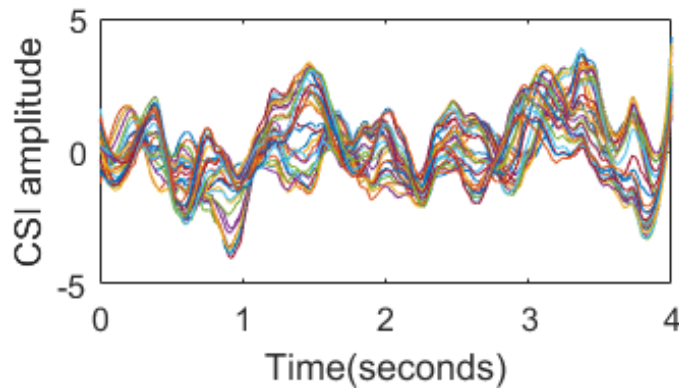☐ Tensor
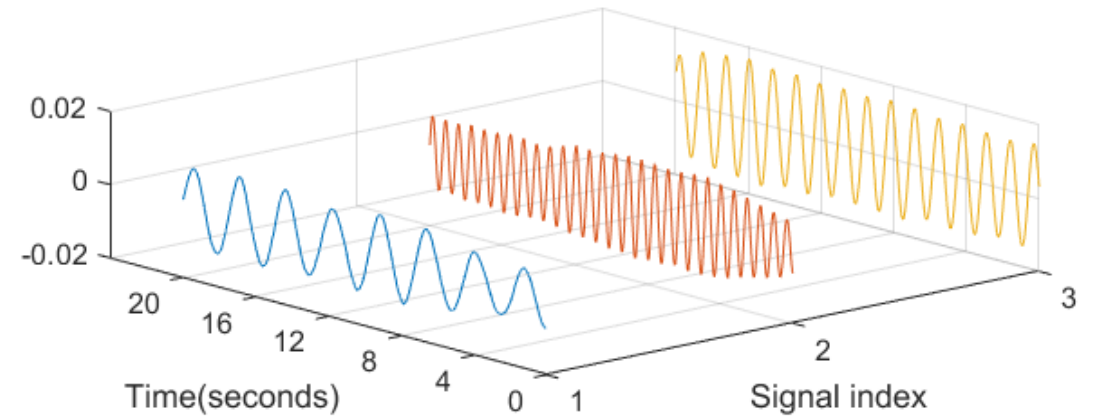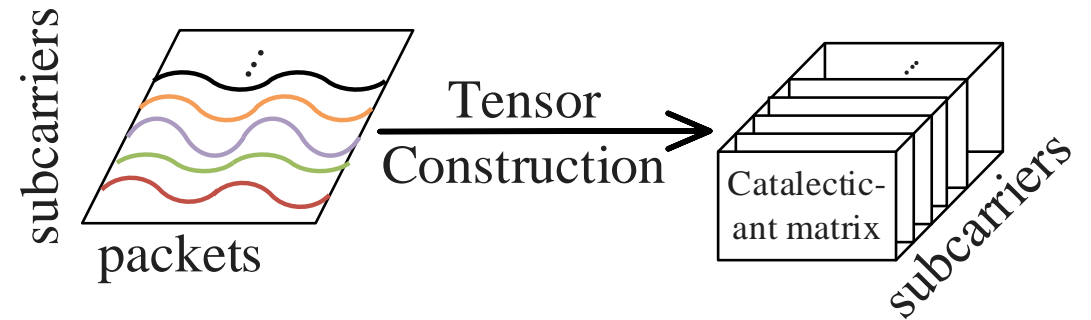
- Keep the structure of the original CSI data

☐ Tensor Decomposition

- Obtain hidden feature components

- Extract physical insight of higher-order tensors

(a) Three runners CSI dynamics

(b) Three runners' running signals fusion

1 Movement Dectection

☐ Observation I: Human movement generates higher mean absolute deviation in CSI measurements than background noise.

$$D_j = \frac{1}{w}\sum_{i=1}^{P}\sum_{k\in S}|a_i(k) - E(a_i(k))|$$

☐ Observation II: The noise level changes slowly over the time. The dynamic threshold algorithm is used to track the noise level.
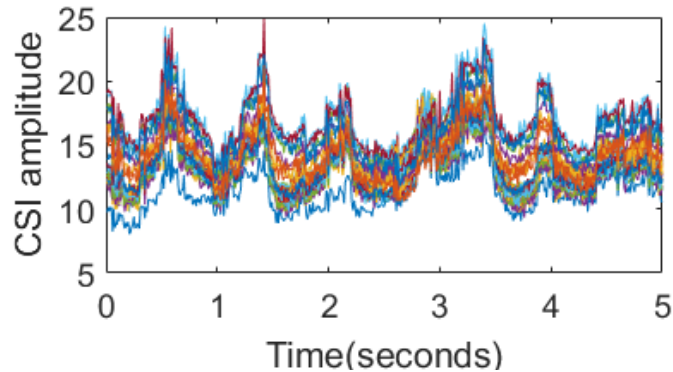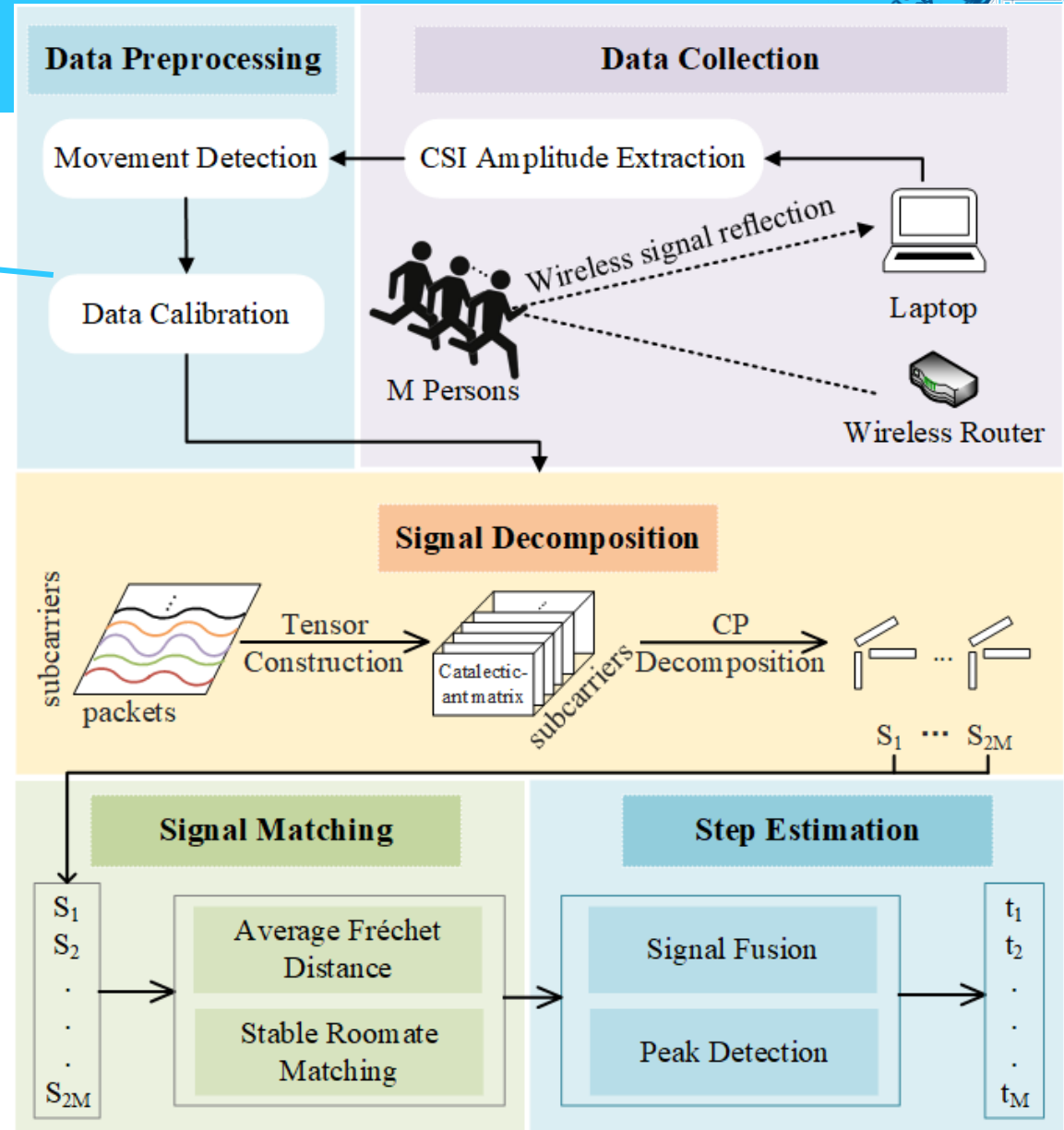
$$N(t) = (1 - \alpha_n)N(t-1) + \alpha_n \times D_j$$
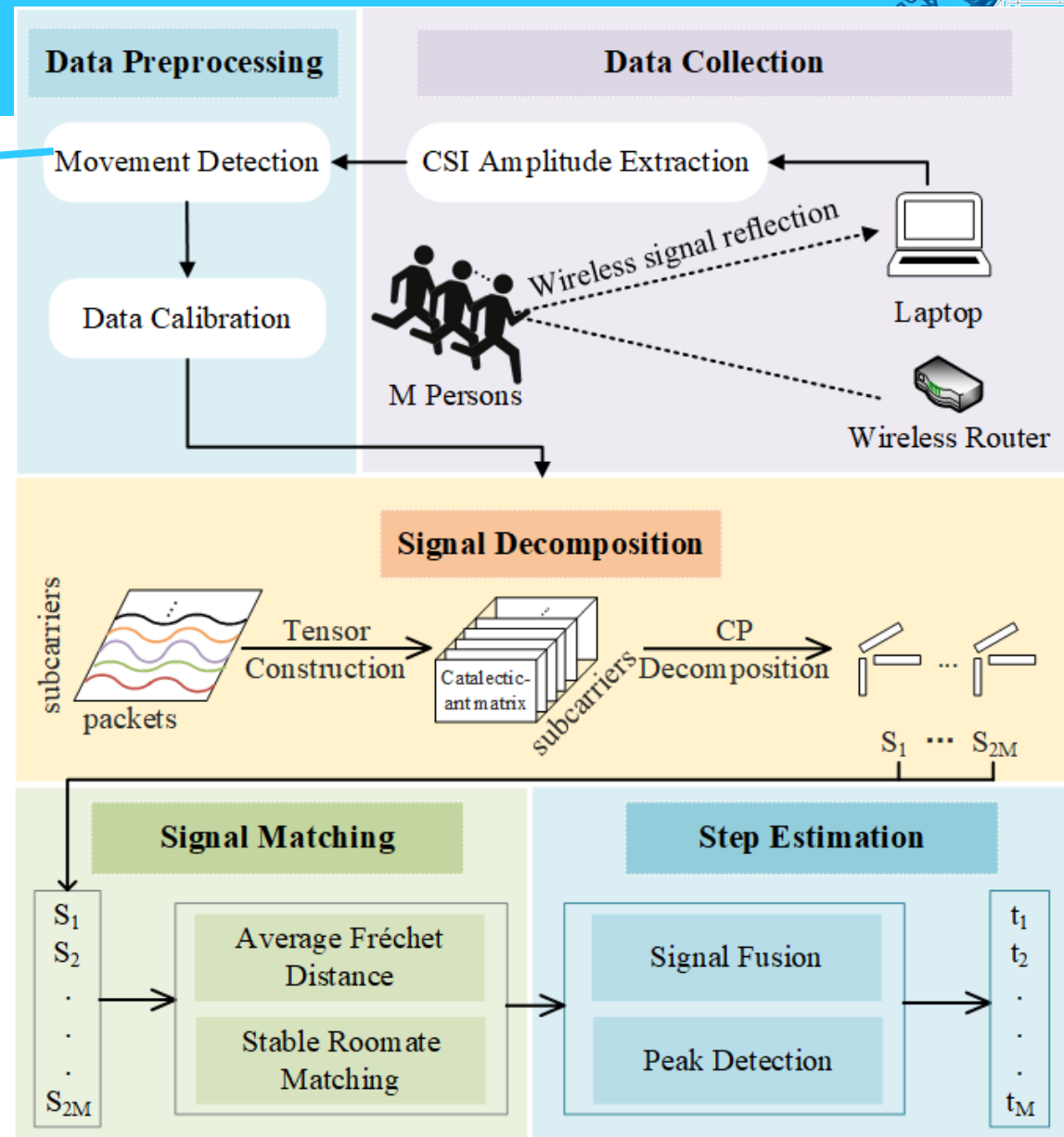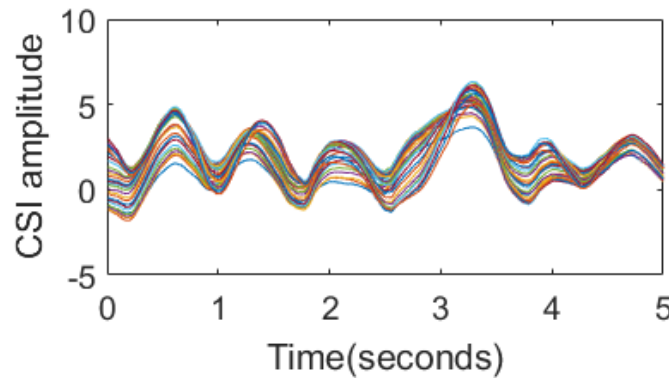
2 Data Calibration

☐ The constant offset is obtained by setting Hampel filter to a large sliding window, and then Savitzky-Golay filter is adopted to smooth out noise while maintains CSI variation.
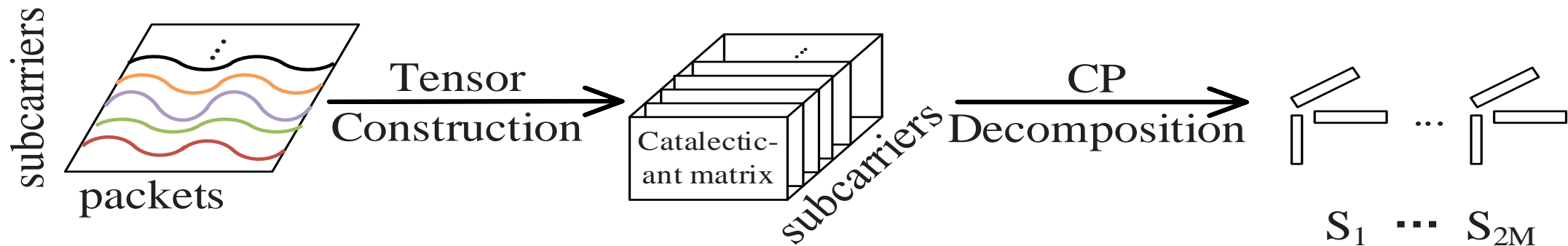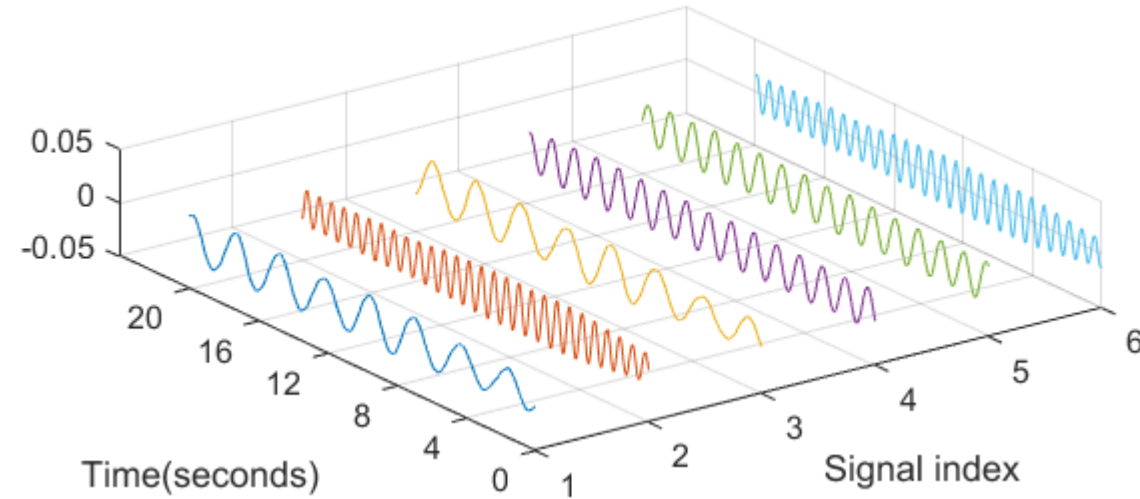
Row CSI

Calibrated CSI

3 Signal Decomposition

□ **Tensor Construction**

- ■ CSI stream to Catalecticant matrix: $a_{ij} = p_{i+j-1}$

- ■ Many streams are palced side by side forming tensor

□ **Canonical Polyadic Decomposition**

- ■ Theorem 1: the number of decomposed parts are 2M

- ■ Theorem 2: the CP decomposition of CSI tensor with rank 2M is to be unique

4 Signal Matching

- ☐ Autocorrelation
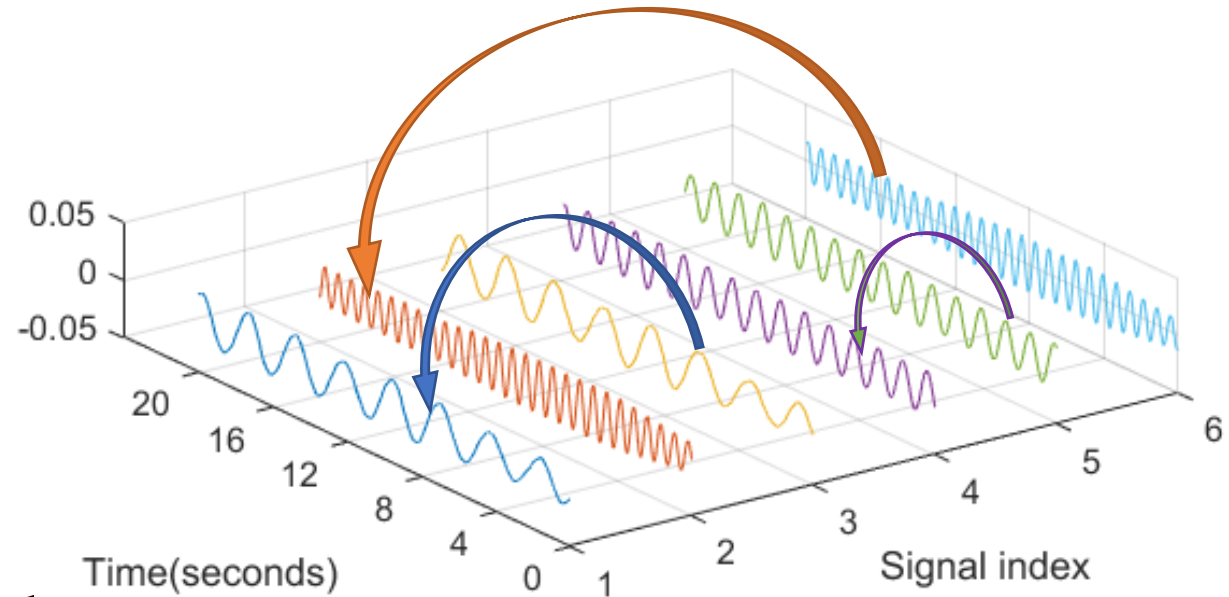
  - ■ Strengthen the decomposed signals periodicity

- ☐ Average Frèchet Distance

  - ■ Calculate the similarity of any pair of running signals

- ☐ Stable Roommate Matching Algorithm

  - ■ Match the pair of autocorrelation signals generated by each runner
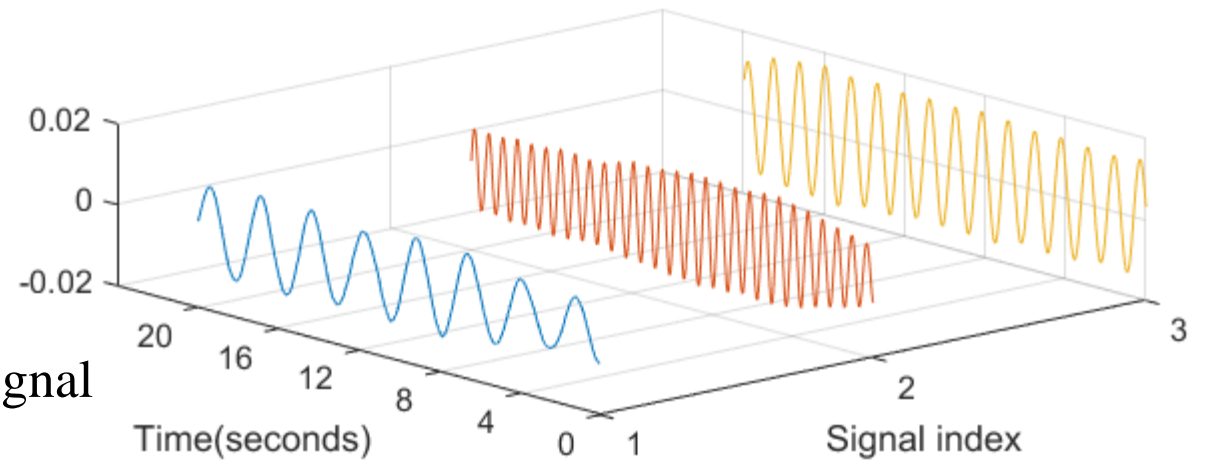
5 Step Estimation

☐ Signal Fusion

- ■ Taking the average of the signal pairs

☐ Peak Detection

- ■ Counting the number of peaks for each person's signal
  - There is hardly fake peak
    - – Smoothness of the catalecticant matrix and CP decomposition

1 Implementation

- ☐ **Evaluation Setup**
    - ■ Two ThinkPad Tseries laptops equipped with Intel 5300 NIC.
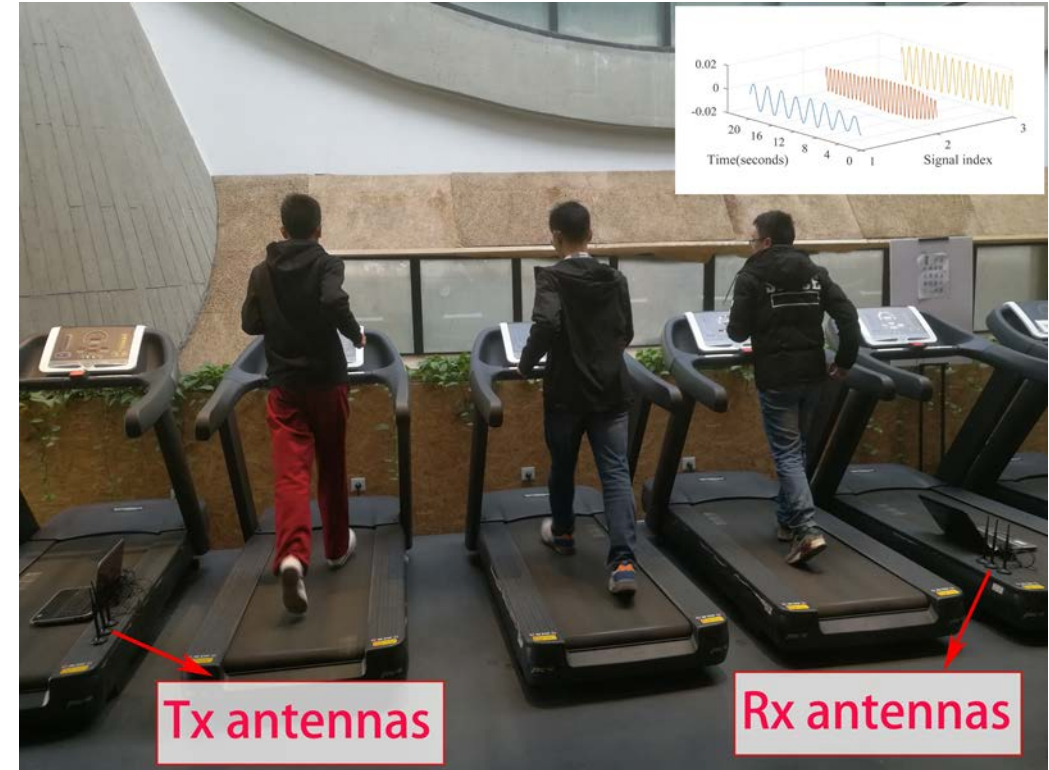
- ☐ **Evaluation Scenario**
    - ■ Gym: size of 15.4×8.7m

- ☐ **Experiment Methodology**
    - ■ Record the experiments by taking HD videos
    - ■ $MEE = \frac{1}{M}\sum_{i=1}^{M}|t_i - \hat{t}_i|, for\ i = 1,2,3,\dots M,$

Tx antennas   Rx antennas

2 Overall Performance

From two to five runners, Wi-Run achieves average estimation accuracy of *91.30%, 90.21%, 86.7%, 84.53%,* *respectively.*
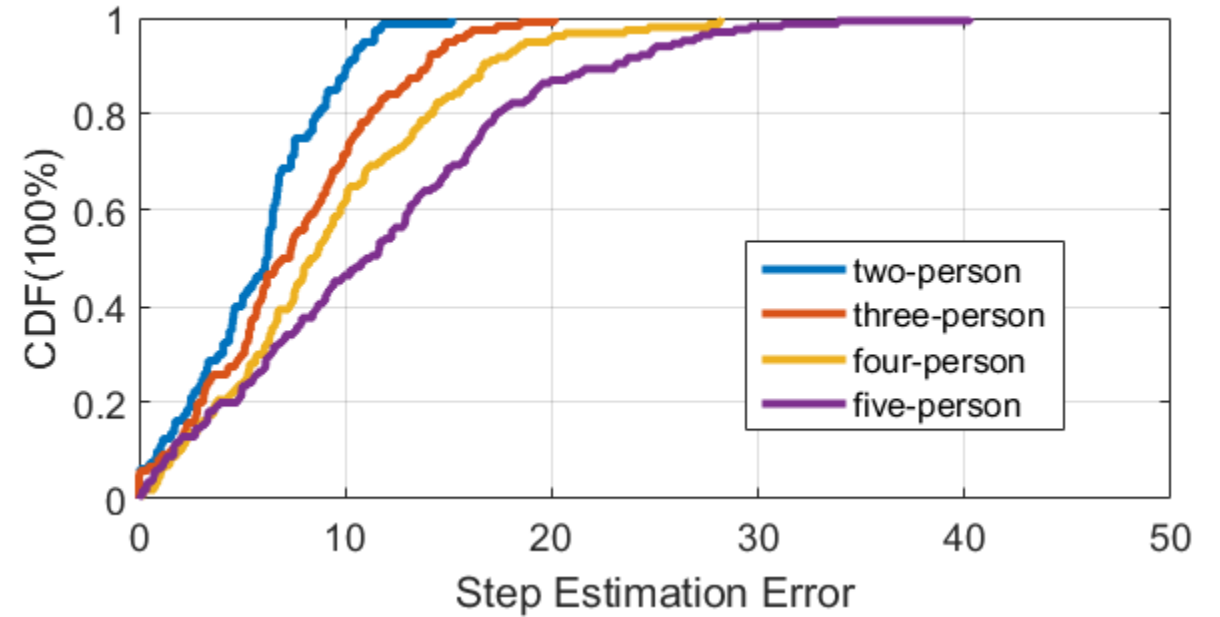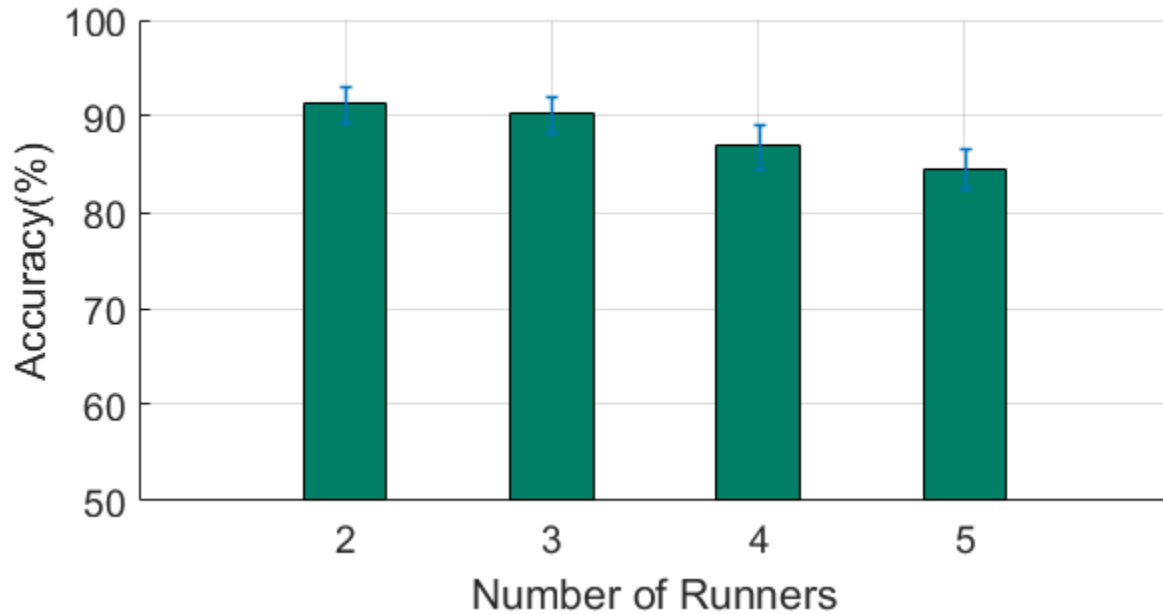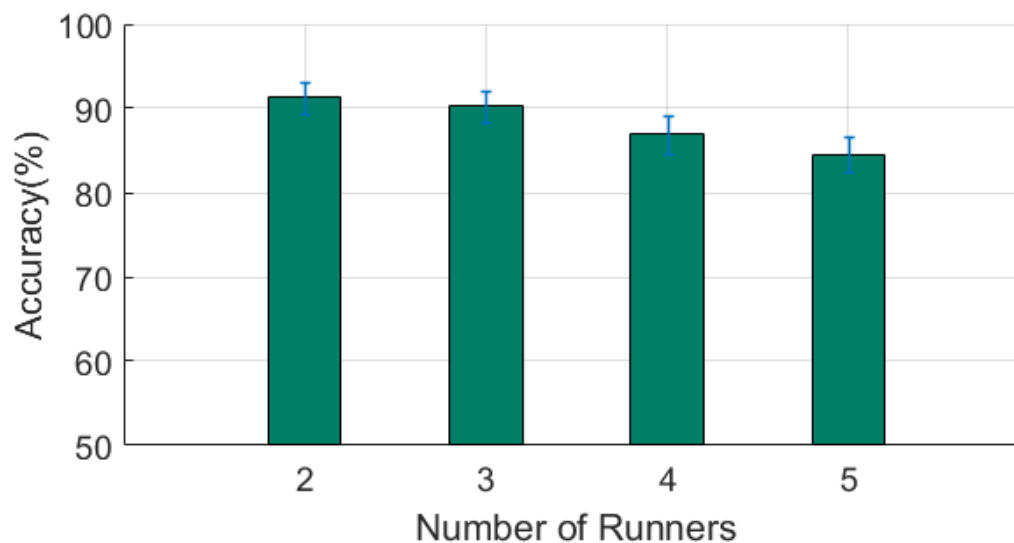
3 Performance Evaluation

☐ Impact of number of runners

■ An additive effect at the receiver side

• Each running induced CSI variation overlays and cancels each other
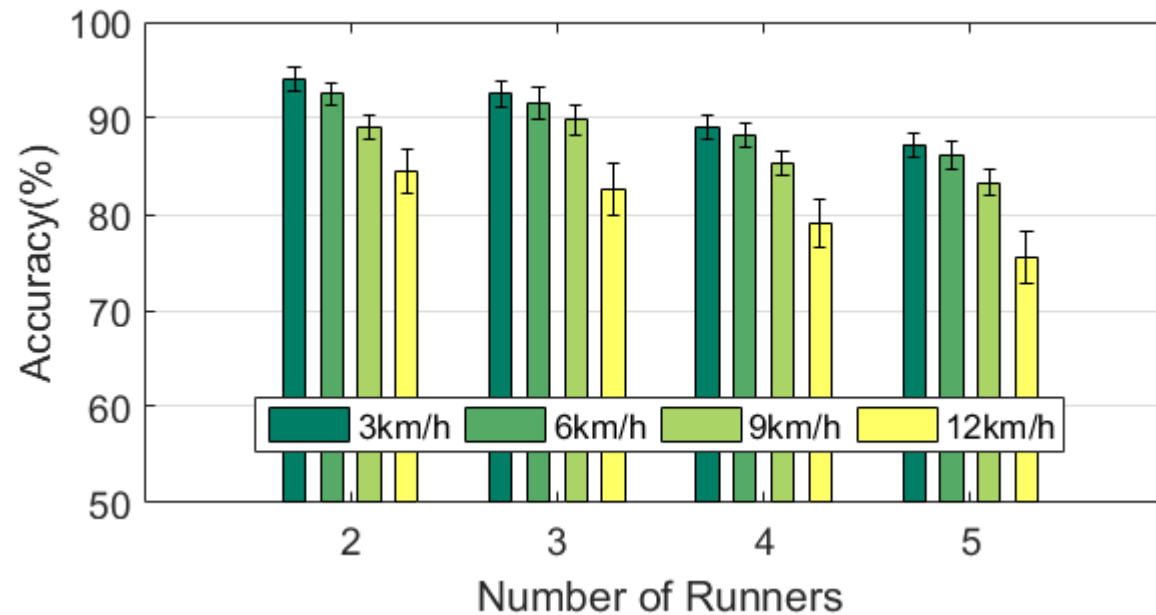
• The reflection of the nearer runner have more power

3 Performance Evaluation

❏ Impact of speed

■ The faster the speed, the more intensive the torso shakes, and more interference
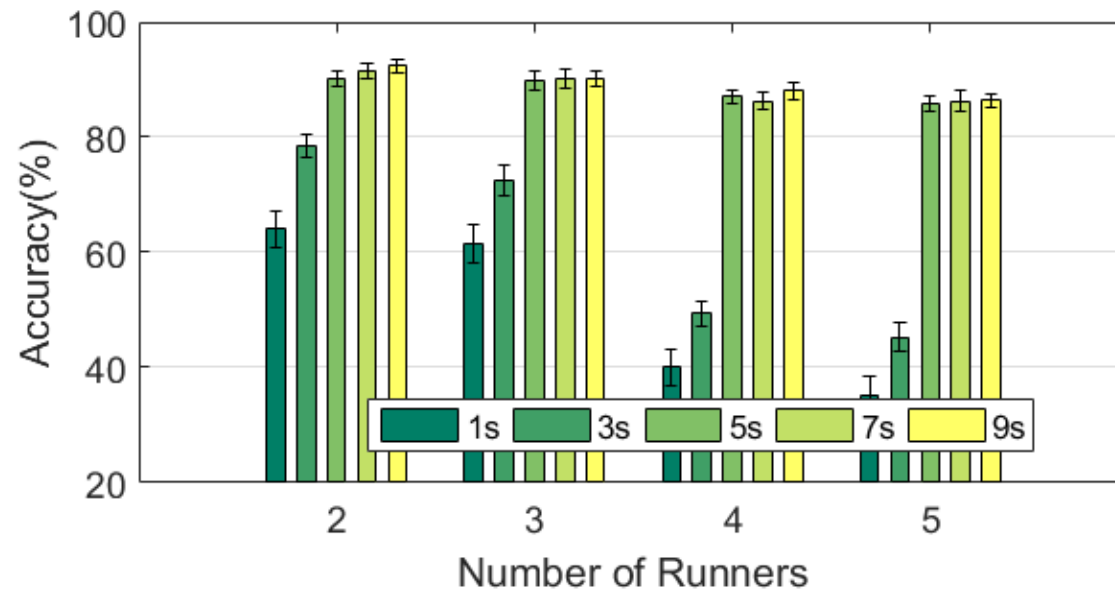
3 Performance Evaluation

☐ Impact of window size

- ■ The time domain resolution is increased

  - Constructing a catalecticant matrix needs plenty of data

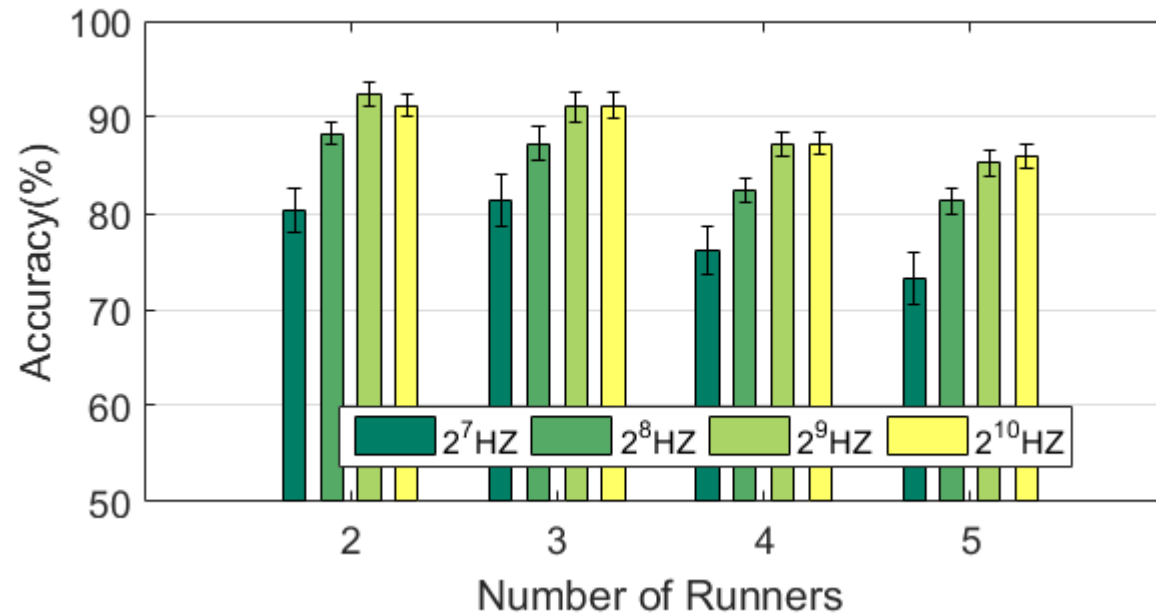 - Half of the data will be taken to smooth the amplitude signals

3 Performance Evaluation

☐ Impact of sampling rate

■ The length of the data for CP decomposition is increased under the contant window size conditions

Conclusion

☐ Wi-Run is the first solution that converges the advantages of purely commercial Wi-Fi, least number of Wi-Fi devices, multi-runner oriented, light-weighted and non-invasive together.

☐ The key challenge is to extract each runner running induced CSI dynamics. To tackle this problem, we theoretically and experimentally verify the feasibility of employing CP decomposition to the multi-person activity induced signal separation.

☐ The extensive experiments demonstrate that Wi-Run performs superiorly with overall step estimation accuracy of 88.25%.

☐ This sheds a promising light on commercial Wi-Fi based complicated human activity monitoring system.

Thank you!

Welcome everybody open to point out

comments and suggestions!