WiFinger: Talk to Your Smart Devices with Finger-grained Gesture

Qualifying Examination

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Introduction

WiFi Signals Can Sense People's Location and Activities

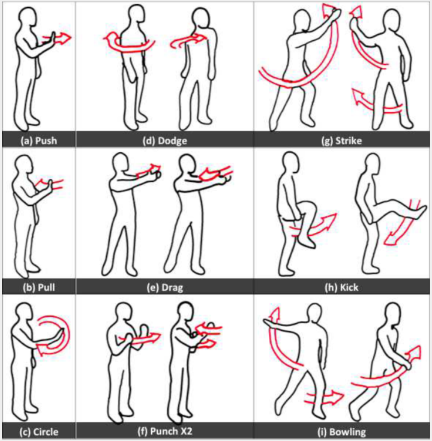

Figure 1: Detecting gestures using WiFi [4]

WiFinger is a wireless system that utilizes commercial WiFi devices to achieve human-computer interaction by recognizing people's finger-grained gestures.

Figure 2: Demonstration of WiFinger [3]

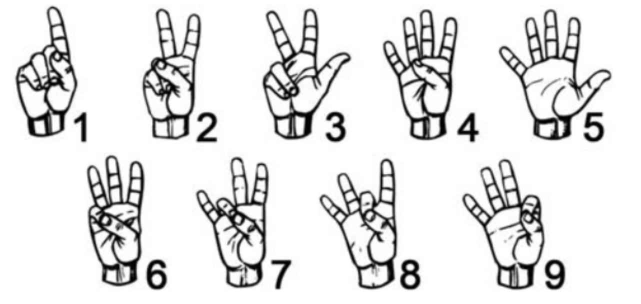

Figure 3: Parts of finger gestures that WiFinger can detect and recognize [3]

Prior (and current) work on gesture detection can be categorized into two groups.

- Device based
  - Audio based
  - Vision based
  - Sensor based
- Device free - Wireless Signal

Received Signal Strength (RSS):
Universal Software Radio Peripheral captures RSS values from WiFi signals [6, 5]. RSS values are not suitable for recognizing fine-grained motions such as gestures in standard American Sign Language (ASL).

Channel State Information (CSI)

- CSI refers to known channel properties of a communication link. The channel between transmitter and receiver comprises of multiple subcarriers.
- is y is the received vector and x is the transmitted vector,

$$y = Hx + n$$

- n is the noise vector. H is the channel frequency response.

Channel State Information (CSI)

$$y = Hx + n$$

The dimension of H is N_c x N_t x N_r.

N_c: Number of sub carriers. N_t: Number of transmit antennas. N_r: Number of receive antennas.

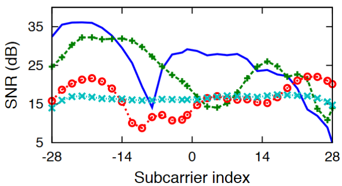

Figure 4: Subcarrier-level signal strength computed from channel state information for four single-antenna 802.11n links [2].

Approach

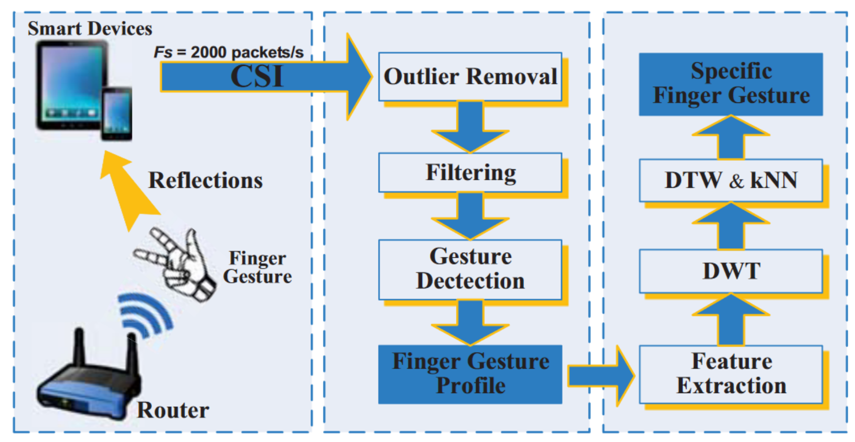

Figure 5: Framework of WiFinger [3]

Signal changes caused by finger motions lie at the low end of the frequency spectrum while noise induced by hardware imperfections has a relatively high frequency.

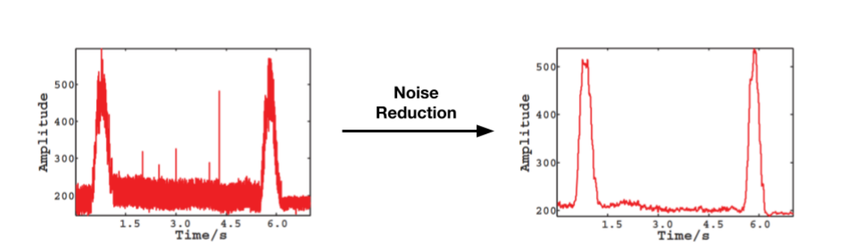

Figure 6: Noise reduction using low pass filter [3]

Preprocessing

- The CSI stream is cut into bins using a sliding window
- The window size is 500.
- Each bin is a matrix of size 30 x 500 $= \mathbf{M}$

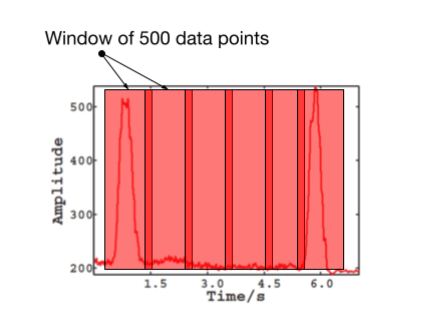

Figure 7: Windowing of the CSI [3]

Correlation Estimation

- WiFinger calculates the correaltion matrix as $\mathbf{M}^T$ x $\mathbf{M}$
- The value of the second eigenvector of the above matrix indicates the presence and absence of a *sign*

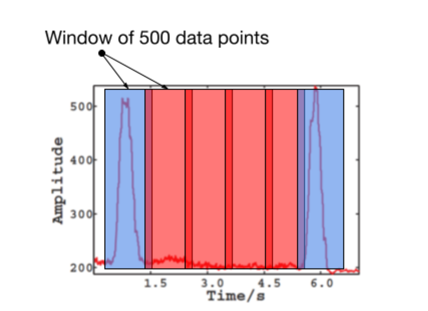

Figure 8: Gesture detected in 2 windows [3]

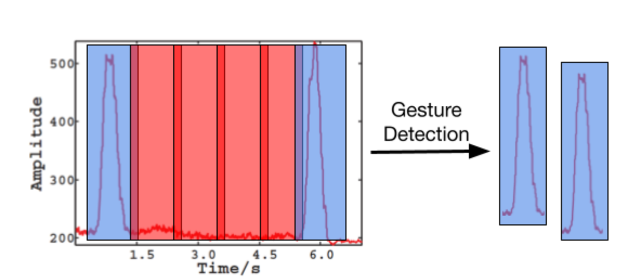

Figure 9: Gesture Profile Extraction [3]

The profile of a particular sign can be mathematically represented as $\mathbf{P_i} = [H_{t_i^s} \ldots H_{t_i^e}]$

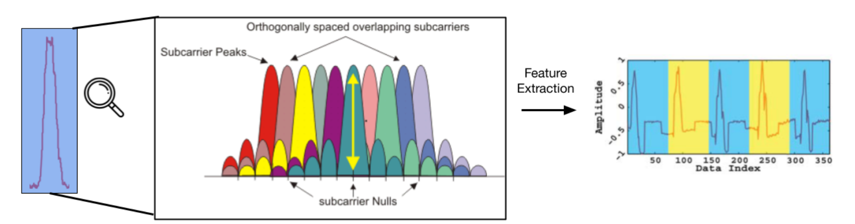

Figure 10: Gesture Feature Extraction [3]

WiFinger combines 30 subcarriers by averaging every 6 subcarriers and then concatenated them to form a synthetic waveform.

WiFinger compresses the feature vectors by utilizing **Discrete Wavelet Transform** (DWT).

- Reduces computational cost compared to Fast Fourier Transform (FFT).
- Preserves both time and frequency domain information.

Classification

- WiFinger utilizes kNN classifier to recognize different finger gestures.
- Feature vector of gestures might not share the same length.

Dynamic Time Warping (DTW) provides intuitive distance between two waveform and can be resilient to signal distortion and shift.

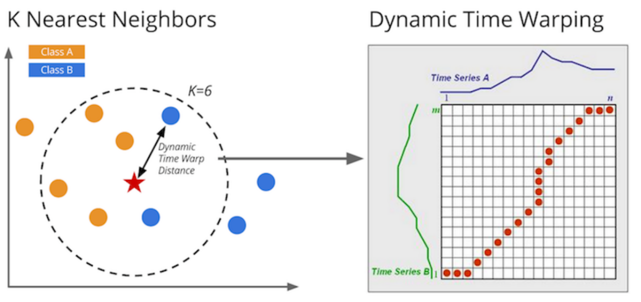

Figure 11: kNN and kNN with DTW[1]

[1]https://github.com/markdregan/K-Nearest-Neighbors-with-Dynamic-Time-Warping

Evaluation and Result

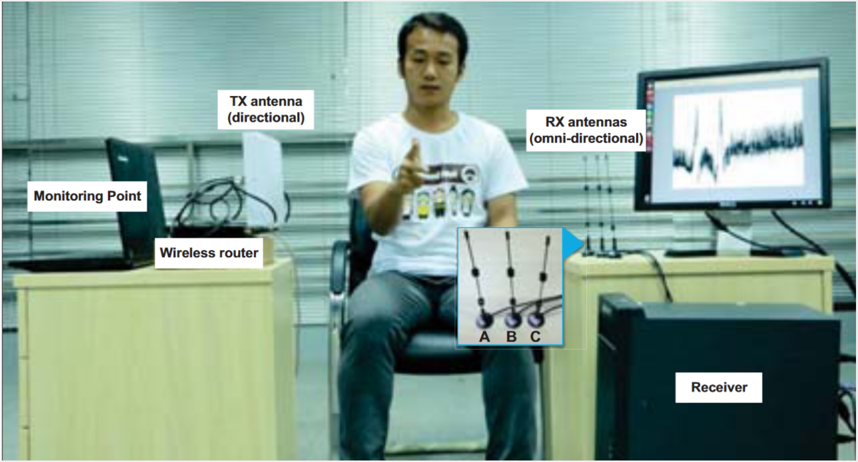

Figure 12: The experimental setup of WiFinger [3]

- 10 users volunteered for the study.
- 9 users performed each gestures 35 times. One user performed each gesture 70 times.

Result

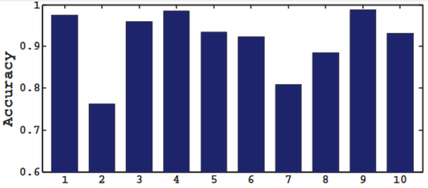

Figure 13: Finger gesture extraction accuracy per gesture for users 1-10 [3]

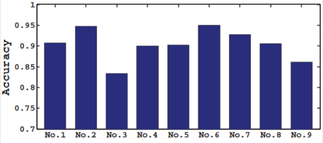

Figure 14: Average recognition accuracy per gesture [3]

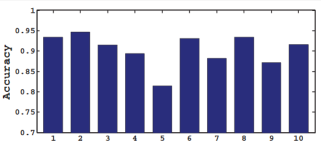

Figure 15: Average finger gesture recognition accuracy per user [3]

Limitations and Summary

Limitations

- Requires line of sight between transmitter and receiver.
- Presence of human body motion, moving objects and the orientation of transceiver impacts the accuracy.
- An environment full of objects (like chair, table etc) reduces the accuracy due to multipath reflections.
- Cannot be used with crowded WiFi bandwidth. For example, 2.5 GHz band is crowded compared to 5 GHz band.
- User demographics are not mentioned.

Summary

- WiFinger exploits the ubiquitous WiFi signals to sense f inger-grained gestures.
- The novelty of the system is the ability to extract fine-grained information from the CSI.
- WiFinger achieves an average recognition accuracy of 90.4% per user.

References

Kamran Ali, Alex X Liu, Wei Wang, and Muhammad Shahzad.
Keystroke recognition using wifi signals.
In *Proceedings of the 21st annual international conference on mobile computing and networking*, pages 90–102, 2015.

Daniel Halperin, Wenjun Hu, Anmol Sheth, and David Wetherall.
Tool release: Gathering 802.11 n traces with channel state information.
ACM SIGCOMM Computer Communication Review, 41(1):53–53, 2011.

Hong Li, Wei Yang, Jianxin Wang, Yang Xu, and Liusheng Huang.
Wifinger: Talk to your smart devices with finger-grained gesture.
In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pages 250–261, 2016.

Qifan Pu, Sidhant Gupta, Shyamnath Gollakota, and Shwetak Patel.
Whole-home gesture recognition using wireless signals.
In *Proceedings of the 19th annual international conference on Mobile computing & networking*, pages 27–38, 2013.

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