Communication Lab

Final Project

Simple Gesture Recognition Using Wireless Signal

Chun-Han Yao

Introduction

As more and more smart home applications are gaining popularity, the demand for whole-room sensing and human gesture recognition rises accordingly. In addition, considering the cost of hardware implementation, it seems more efficient to utilize the existing wireless systems and perform recognition via analyzing real data signals.

In this project, we propose a gesture recognition system using wireless signal transmission, which evaluates the Doppler frequency shift caused by human motion and match with the profile of each pre-defined gesture. As a result, our system achieves 84% accuracy for one-dimensional gestures (e.g. push and pull), and 68% accuracy for two-dimensional gestures (e.g. waving hands horizontally).

Reference work – WiSee [1]

Pu *et al*. proposed a gesture recognition system, WiSee, which leveraged Wi-Fi signals to enable whole-home sensing and recognition of human gestures. Since a 0.5m/sec movement will only cause a maximum Doppler shift of 17Hz on a 5GHz carrier, we need to detect frequency shifts of a few Hertz from the 20MHz Wi-Fi signal. Hence, the major task is to create narrowband pulses from each OFDM sub-channel. The details of recognizing gestures can be summarized into the following steps:

1. Perform a **large FFT over an one-second duration** and create an one-Hertz wide narrowband signal from each OFDM sub-channel. Figure 1 shows the waveform of OFDM sub-channels.

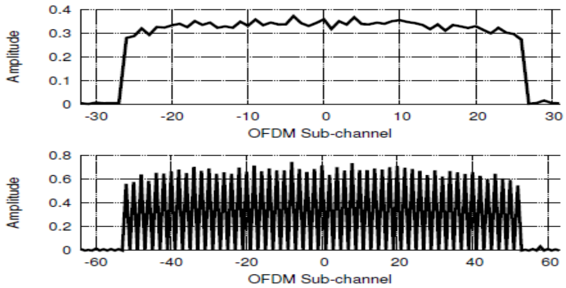


Figure 1. waveform of the OFDM channel

2. **Average the Doppler shifts** observed across all sub-channels to reduce the noise.
3. Design a data-equalizing re-encoder that **transforms each OFDM symbol into the same symbol**.
4. Track the **time-frequency Doppler profile**. Figure 2 shows the time-frequency Doppler profile of push.

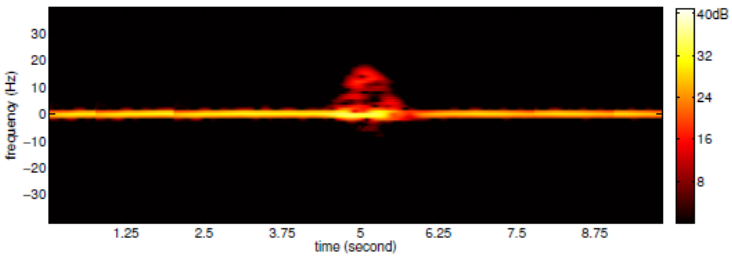


Figure 2. The time-frequency profile of push

5. Match the observed profile with that of each pre-defined gesture.
6. Figure 3 shows the accuracy WiSee achieves. It can be seen that the accuracy increases with the number of the antennas.

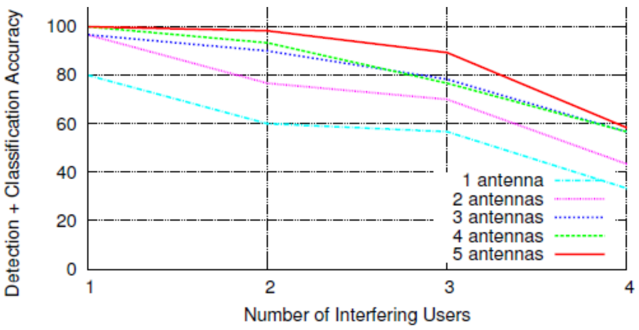


Figure 3. Accuracy

- **System implementation**

The system is implemented by LabVIEW tools and two USRP devices connected by a MIMO cable. Each USRP has one Tx antenna and one Rx antenna, and receives the wireless signal transmitted by itself. The hardware setup is shown is Figure 4.

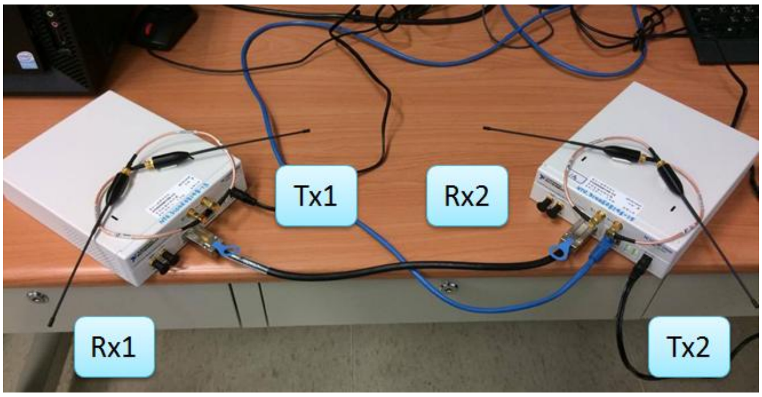


Figure 4. Hardware setup

With the control of LabVIEW tools, same symbol (1kHz sine wave on 2GHz carrier wave) is transmitted and received permanently by the USRPs devices. After receiving the signal, we do large FFT over an one-second duration, extracting the PSD in the interested range (960 – 1040 Hz). Finally, gesture recognition can be done by evaluating the Doppler shifts. Figure 5 shows the control panels and block diagrams on LabVIEW.

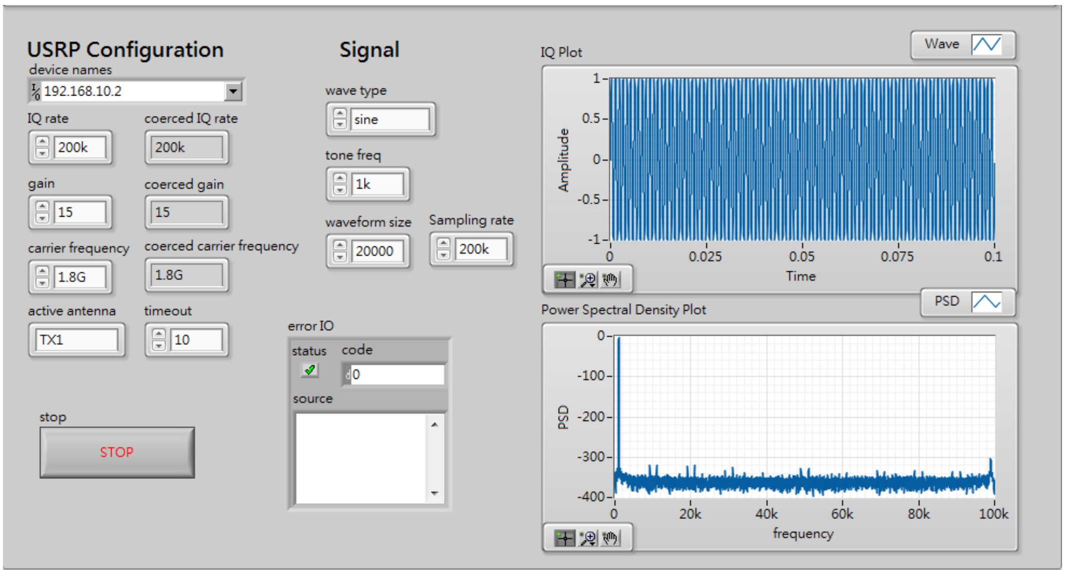


Figure 5.1 Control panel of the transmitter

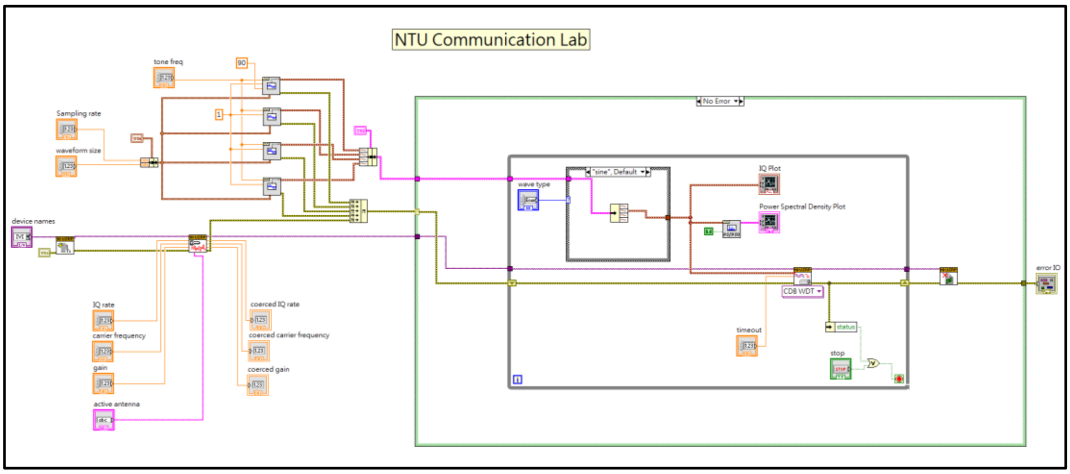


Figure 5.2 Block diagram of the transmitter

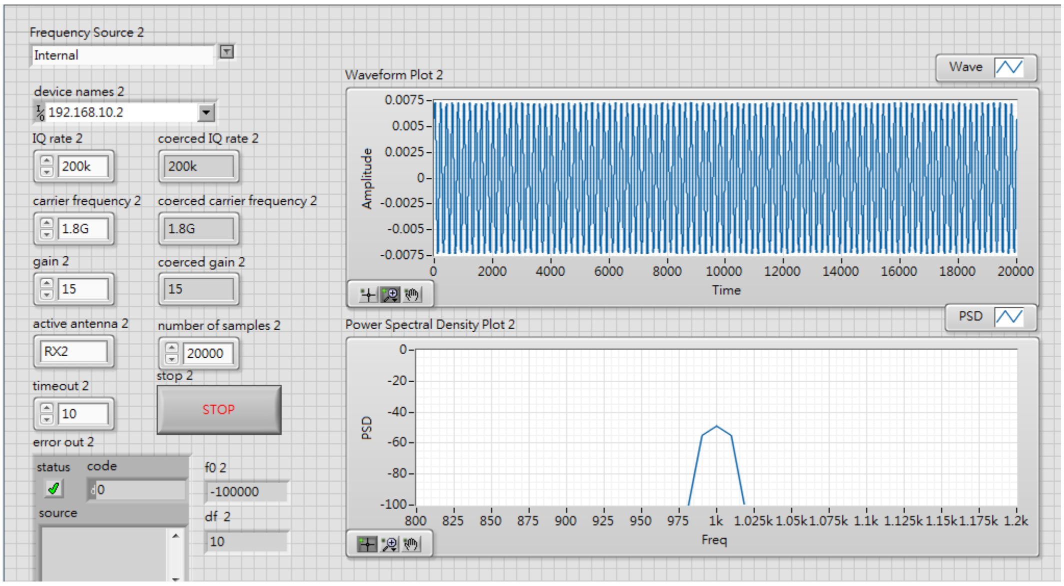


Figure 5.3 Control panel of the receiver

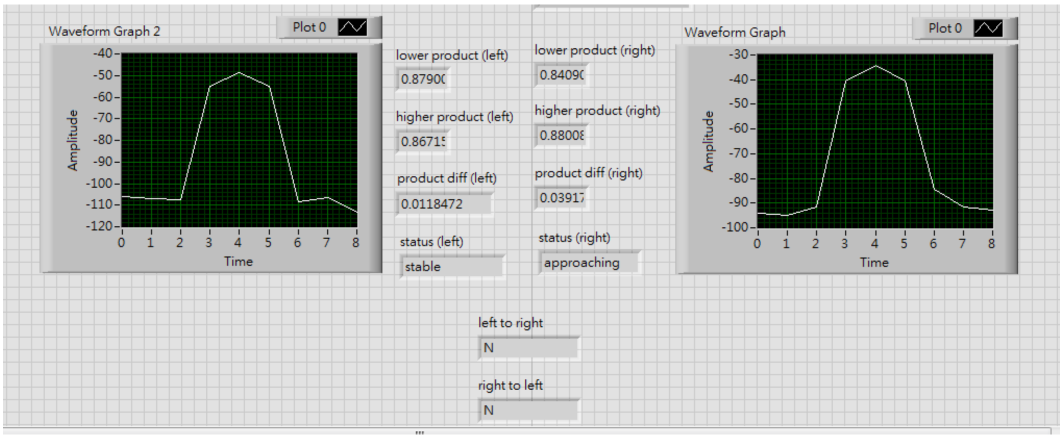


Figure 5.4 Control panels of two receivers showing the PSD in the interested frequency range and the results of recognition.

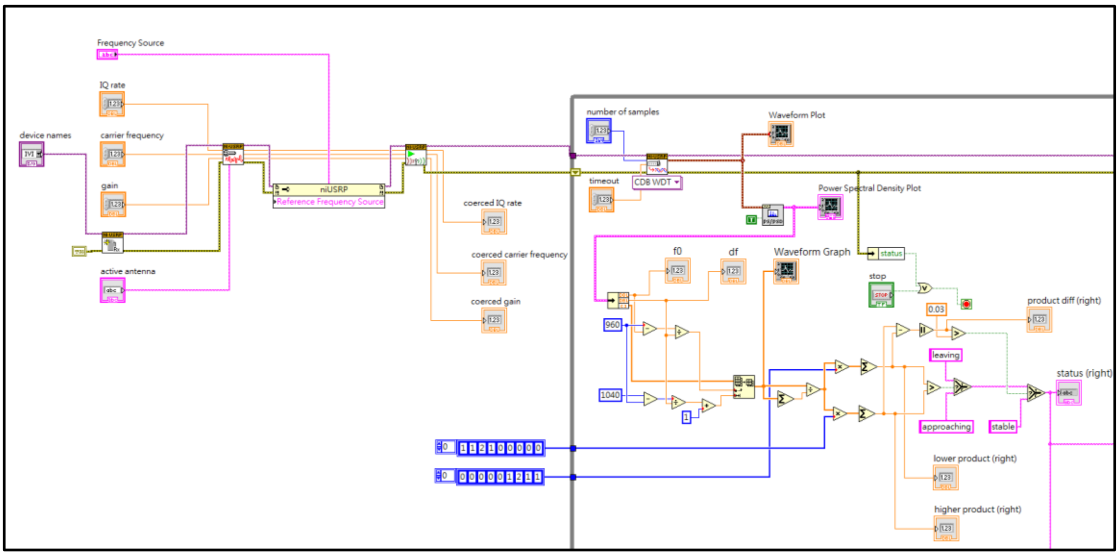


Figure 5.5 Block diagram of the receiver

First, the raw PSD is normalized to prevent noise. Then, for each USRP, we determine if the Doppler shift is large enough. If yes, a positive Doppler shift indicates an approaching movement, while a negative Doppler shift indicates a leaving movement. Combining the two USRP, we can recognize movements of another dimension, such as waving hands horizontally. The block diagrams of recognition are shown in Figure 6.

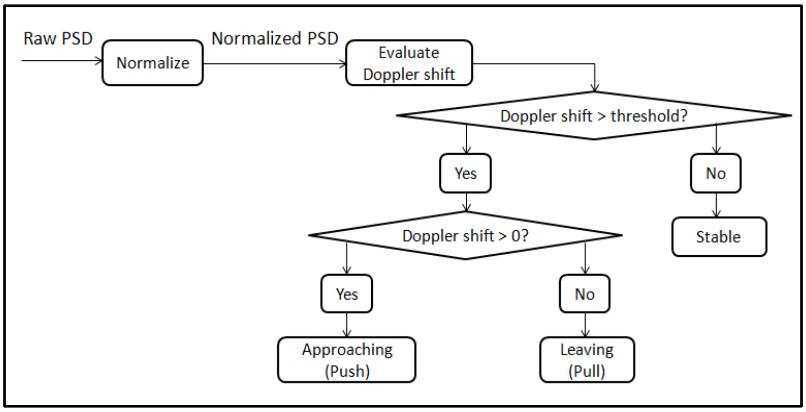


Figure 6.1 Block diagram of recognizing pull and push

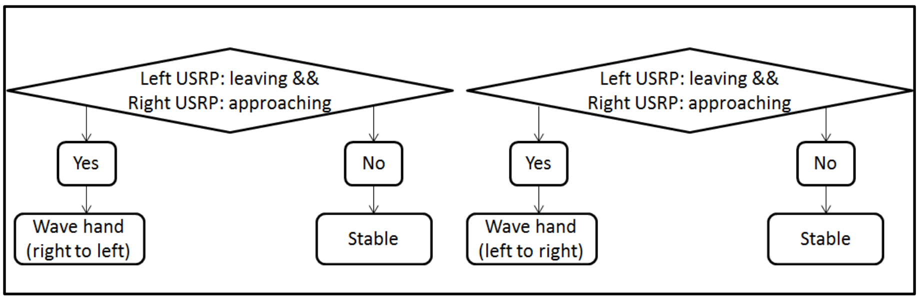
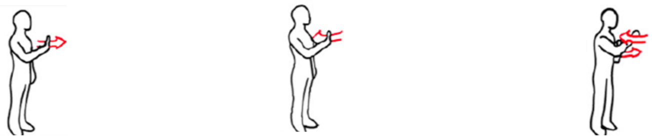


Figure 6.2 Block diagram of recognizing waving gestures

- **Main achievements**

With single USRP, we can recognize gestures with one-dimension, such as push, pull and punch. With two USRP, we can deal with two-dimensional gestures like waving hands horizontally (left to right / right to left). Figure 7 demonstrates the gestures mentioned.

1. Push 2. Pull 3. Punch



4. Waving from left to right 5. Waving from right to left

Figure 7. Demonstrations of gestures

- **Experimental Results**

In the experiments, we seek to discover the correlation between the accuracy of recognition and the following factors: 1. Distance between human and USRP devices. 2. Velocity of human motion. 3. Angle between Tx and Rx antennas.

1. **Accuracy – Distance** (motion velocity = 1m/sec, antenna angle = 100°)

	0.3m	1m
Push	82%	50%
Pull	82%	58%
Left to right	54%	X
Right to left	54%	X

2. **Accuracy – Motion velocity** (distance = 0.3m, antenna angle = 100°)

	Fast (1.5m/sec)	Medium (1m/sec)	Medium (0.5m/sec)
Push	80%	82%	90%
Pull	80%	82%	92%
Left to right	28%	54%	56%
Right to left	28%	54%	62%

3. **Accuracy – Angle between antennas** (distance = 0.3m, motion speed = 1m/sec)

	60°	80°	100°	120°
Push	92%	72%	82%	84%
Pull	88%	76%	82%	80%
Left to right	62%	64%	54%	58%
Right to left	60%	68%	54%	60%

● Discussions

1. Accuracy - Distance

   Since the system is **sensitive to noise**, the accuracy of gesture recognition drops drastically with the distance between human body and USRP devices.

   For gestures which require multiple USRPs, the accuracy becomes poor since the **distance between two USRPs is limited by the MIMO cable**.

2. Accuracy - Motion velocity

   When detecting gestures like push and pull, which requires only one USRP, the accuracy remains high regardless of the speed of hand movements.

   However, for gestures like waving hands, the system recognizes them accurately only when the Doppler shift caused by the motion is within the **target frequency range** (960-1040Hz).

   For example, if the waving is too fast, it will cause a 60Hz frequency shift. But in our system, we only detect the frequency in range of 960 to 1040 Hz. Hence, the accuracy decreases.

   Furthermore, when detecting waves, the system needs to recognize two gestures simultaneously (pull and push in two USRPs). So if the movement velocity is too high, **the USRP devices can't react to the drastic change in time due to system limit**, which also affects the accuracy.

3. Accuracy – Angle between antennas

   The recognition of push and pull achieves a highest accuracy when the angle between Tx and Rx antennas is 60°. However, the accuracy of recognizing waving hands is highest when the angle is 80°. It's probably affected by the **direction of transmitted wave from the antennas**.

Reference

[1] Pu, Qifan, et al. "Gesture Recognition Using Wireless Signals." *GetMobile: Mobile Computing and Communications* 18.4 (2015): 15-18.