Hand Gesture Recognition Based on Wi-Fi Chipsets

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***Abstract* — Hand gesture recognition (HGR) based on radar technology is becoming a hot topic recently. In this paper, we utilize a regular Wi-Fi transceiver chipset to construct a coherent radar sensor. The direct conversion and digital baseband signal processing technologies are used to detect hand motions with specific signatures. Experiments based on a dual-channel receiver aiming to detect two-dimensional motions are conducted, and the results show promising potentials in HGR applications.**

***Index Terms* — Pattern recognition, Wi-Fi, radar sensor.**

I. Introduction

Hand gesture recognition (HGR) is one of the most natural ways of machine input in contrast with conventional human-machine interaction (HMI) devices such as mouse and keyboards. HGR is originally a topic in the area of computer science, and it is usually based on cameras and computer vision algorithms [1], which relies on complicated digital image processing techniques, and thus camera based HGRs would significantly consume computational resources. Besides technical challenges in realizing the image processing algorithms, the high demand in computational resources is a major factor that constraints the computer vision based HGRs from being widely adopted in daily life.

Radar sensors based HGRs detect the Doppler effect caused by the radio frequency (RF) signals scattered off moving objects, beginning to attract significant interests in microwave engineering recently. Having properties of simple structure, high sensitivity, these radar sensors have exhibited promising potentials in different applications in the past years, such as human vital sign and gait detections, mechanical vibration measurements, search-and-rescue, through-the-wall life detection, and monitoring of blood flow in the cardiovascular system. And Single-chip integrations of the RF front-ends have been reported. But only a few researches in this area are related to HGRs [2]-[5]. One example is the experimental demonstration at 60 GHz by Google Soli team [5].

On the other hand, Wi-Fi functions have been equipped in most intelligent devices. It includes a transmitting path and a receiving path similarly to a radar sensor. Therefore, it is possible to implement some radar functions within the present Wi-Fi architecture in some degree. As is shown in Fig. 1, HGR can be a good machine input method for intelligent devices especially smart watches which have miniature screen. We can define several specific hand gestures, and use machine learning and pattern matching to recognize them. Since the Wi-Fi system can be regarded as a software definition radio (SDR) platform, we can modify the waveform within the Wi-Fi ISM bandwidth to detect the Doppler effect scattering off by the moving object while transmitting a message. However, most conventional Wi-Fi hardware is half duplex, which means we cannot receive a signal while transmitting. In this case we have to slightly modify the Wi-Fi architecture or to use the asynchronous micro-Doppler detection method.

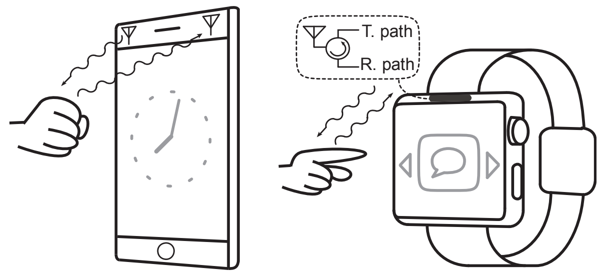


Fig. 1. Assumed Wi-Fi based radar function implemented in intelligent devices.

In Fig. 1, two antennas are used to separate the transmitting and receiving paths. Since the size of today's handheld device is normally too small to avoid crosstalk between the two antennas, higher frequency such as 5.8GHz or 24GHz can be used. For space limited application like smart watch, a miniature circulator is another way to avoid coupling, where transmitting and receiving antennas can share the same antenna.

In this paper, we investigate the feasibility to implement HGRs based on a Wi-Fi chipset, and then discuss a possible method of two-dimensional motion detection. The purpose of this work is to recognize two basic signatures of moving and clicking by remotely imaging the hand's motion with dual receiving channels.

II. Architecture and Algorithms

A. System Architecture

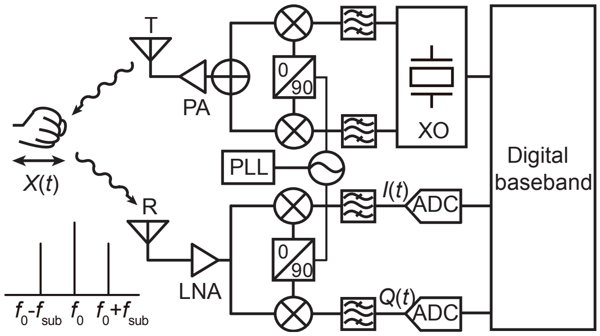


Fig. 2. Wi-Fi chip based radar with Coherent zero-IF structure.

The modified Wi-Fi architecture uses a quadrature direct conversion architecture as shown in Fig. 2. In this paper, we choose a sine-wave crystal oscillator (XO) to generate the transmitting baseband IQ signal.

It is well known that for a quadrature direct conversion receiver detecting a target with motion $X(t)$, the baseband outputs from the in-phase (I) and quadrature-phase (Q) channels can be expressed as

$$I(t)=A_I(t)\cos\left[\theta_0+\frac{4\pi X(t)}{\lambda}+\varphi_0(t)\right]+DC_I(t), \tag{1}$$

$$Q(t)=A_Q(t)\sin\left[\theta_0+\frac{4\pi X(t)}{\lambda}+\varphi_0(t)\right]+DC_Q(t), \tag{2}$$

where $DC_I(t)$ and $DC_Q(t)$, $A_I(t)$ and $A_Q(t)$ denote the DC offsets and the amplitudes of the output I/Q signals, respectively. In the brackets, λ, $\varphi_0(t)$ and θ_0 denote the wavelength of the continuous wave, the added phase noise of the transceiver, and the nominal phase delay between the transmitted and received signal, respectively.

Clearly, the target motion can be mathematically solved from (1) and (2) as

$$X(t)=\frac{\lambda}{4\pi}\left\{\arctan\frac{\left[Q(t)-DC_Q(t)\right]/A_Q(t)}{\left[I(t)-DC_I(t)\right]/A_I(t)}-\theta_0-\varphi_0(t)\right\}. \tag{3}$$

In this paper's hardware implementation, the transmitter emits a subcarrier modulation wave, which has a spectrum with two sidebands symmetrically located near the LO frequency f_0 as shown in the inset of Fig. 2. The transmitted subcarriers are scattered by the moving object and background clusters, and the received signal is directly down-converted by the same LO, achieving a coherent, quadrature zero-IF conversion, and the demodulated subcarriers carrying the motion information can be digitized by two ADCs. Finally the linearized arctangent algorithm discussed above or the extended DACM algorithm [6], [7] can still be used to retrieve the motion $X(t)$ as long as the subcarrier f_{sub} is down converted to zero by band-pass sampling technique.

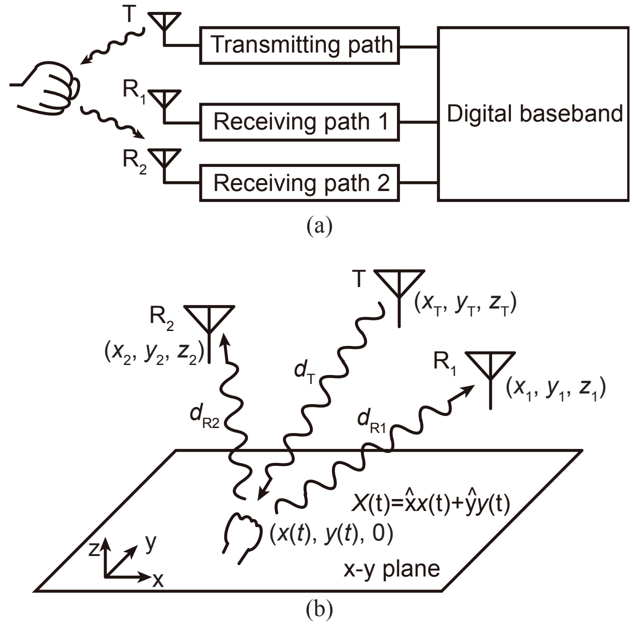


Fig. 3. (a) Block diagram of radar with one transmitting path and two receiving path. (b) Two dimensional detection analysis model.

B. Two dimensional imaging Algorithm

Fig. 3 (a) shows the adopted structure containing one transmitter and two receivers for HGR, sharing the same digital baseband. Fig. 3 (b) shows the analysis model for the 2-D motion imaging. Assume the object is limited to move in the x-y plane with an instantaneous location ($x(t)$, $y(t)$, 0). The transmitting antenna T located at (x_T, y_T, z_T) and two receiving antennas R_1 and R_2 located at (x_1, y_1, z_1) and (x_2, y_2, z_2), respectively. The distances between T, R_1, R_2 and the moving object are denoted as d_T, d_{R1} and d_{R2}. In this case, the round-trip distance between the transmitting antenna and the two receiving antennas are $d_1 = d_T + d_{R1}$, $d_2 = d_T + d_{R2}$, respectively. At any time, the scatterer must be located at a point intersected by the x-y plane and the surfaces of two ellipsoids with focuses at the locations T, R_1 and T, R_2. The corresponding ellipsoid functions are

$$\begin{aligned}&\sqrt{\left(x_T-x(t)\right)^2+\left(y_T-y(t)\right)^2+z_T^2}\\&+\sqrt{\left(x_1-x(t)\right)^2+\left(y_1-y(t)\right)^2+z_1^2}=d_1,\end{aligned} \tag{4}$$

$$\begin{aligned}&\sqrt{\left(x_T-x(t)\right)^2+\left(y_T-y(t)\right)^2+z_T^2}\\&+\sqrt{\left(x_2-x(t)\right)^2+\left(y_2-y(t)\right)^2+z_2^2}=d_2,\end{aligned} \tag{5}$$

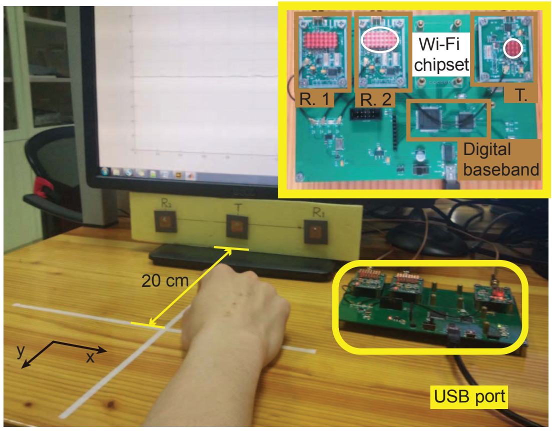
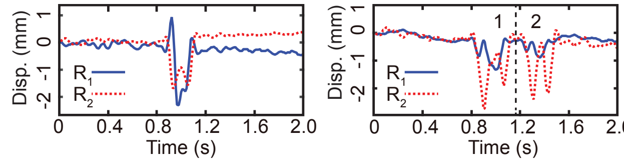
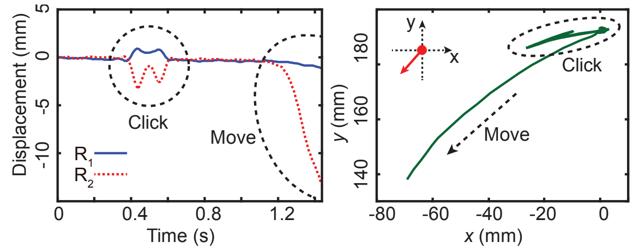


Fig. 4. Experimental setup for HGRs, the inset shows the hardware implementation.



(a)



(b)

Fig. 5. Wi-Fi based radar with Coherent zero-IF structure.

respectively.

By solving the equation (4) and (5), the location of the object at any time can be obtained, where d_1 and d_2 are the sums of the initial d_0 and the respective displacement of each channel. Therefore, if the initial location of the motion is known, the real time motion can always be obtained by continuously calculating the intersection points for each time step. As indicated, assisted by the dual subcarriers, the initial location can be obtained using the dual-frequency localization method proposed in [8].

Using the above architecture and algorithms, we are able to implement the 2-D motion imaging for hand and fingers motion on the surface of a table.

III. Measurement and Discussion

Fig. 4 shows the experimental setup for HGRs, in which antennas were places on the lower edge of a monitor n a line with 10 centimeter spacing. A hand is moving in a rectangular area 20 cm away from the transmitting antenna. A small power is transmitted so that reflections form distant objects would not notably interfere the reflection from the moving hand. Fig. 5 shows the experimental result, from Fig. 5 (a) we can easily identify the click and double-click motion. Fig. 5 (b) shows an example of measured complex motion including a click and a moving not aligned with the cross lines. The click and the moving actions can also be clearly identified.

IV. Conclusion

In conclusion, we have investigated the feasibility to implement a HGR system based on Wi-Fi single-chip transceiver chipsets building a cost-effective hardware. A two-dimensional motion imaging algorithm are proposed to linearly reconstruct the hand and finger motions from the demodulated Doppler phase shifts. Experimental measurements verified the effectiveness of the Wi-Fi based architecture and the proposed algorithm, exhibiting promising potentials for practical applications as one of the miniatuer smart devices's input choices.

Acknowledgement

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