Design of Gesture Recognition System Based on 77GHz Millimeter Wave Radar

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***Abstract*-In this paper a gesture recognition system based on millimeter wave radar (MMW) will be presented. The radio frequency (RF) transceiver circuit is built with the TI-manufactured AWR1443 highly integrated frequency modulated continuous wave (FMCW) RF transceiver chip which has an operating frequency of 76-81 GHz, a 3-channel transmitter, and a 4-channel receptor. The antenna array is constructed with a 1 x 16 microstrip antenna. The deep learning is conducted using TensorFlow on the sample data acquired from an ADC sampling done at the radar front-end section, which ultimately realizes the function of gesture recognition.**

I. INTRODUCTION

MMW radars are uniquely advantageous in a number of ways [1]. First of all, it can realize high-precision positioning (speed measurement, distance measurement, and angle measurement). Secondly, a compact and economical MMW sensor can be built thanks to its high frequency and the small antenna [2]. Compared with laser and ultrasonic radars, MMW radar has low atmospheric decay and loss in the transmission window as well as strong penetrability, allowing it to meet the requirements for all-weather adaptability [3-5]. In this paper, a microstrip antenna and a 77 GHz radar circuit of MMIC were used, and the signal processing part was equipped with a Cortex-R4F microcontroller, allowing the calculation of fast Fourier transform (FFT) and the implementation of constant false alarm rate (CFAR) algorithm, angle estimation, and other data processing process directly on the panel, thereby reducing the volume of the radar system.

II. RADAR HARDWARE SYSTEM

The radar hardware system was comprised of an antenna array and an RF transceiver circuit. The signal source emitted sawtooth wave modulation signal, followed by the implementation of ADC sampling of the received signal and mixed intermediate frequency (IF) signal; the object distance, speed, and other information were then obtained through the one-dimensional (1D) and two-dimensional (2D) FFT of the sample data; then the azimuth angle and the elevation were estimated to calculate the spatial position of the object. The test data were then sent to the computer via a serial port. The design of the radar system is specifically explained as follows.

A. Antenna Array

Fig. 1 shows the 1 x 16 microstrip antenna model, and Fig. 2 shows the S_{11} simulation results of the simulated antenna. The lowest point of S_{11} is (77.12 GHz, -48.2dB), the bandwidth is 860 MHz, and the maximum gain is 16.8 dB.

Fig 1. 1 x 16 antenna model

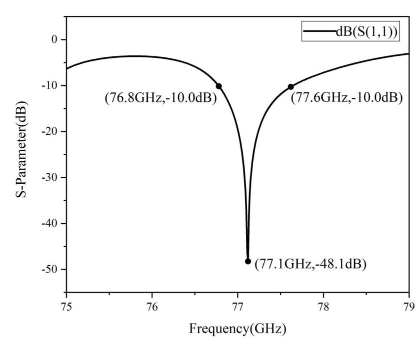
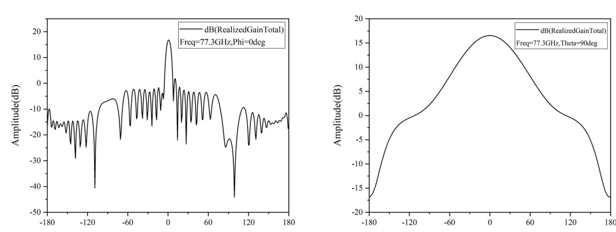


Fig 2. S_{11} of the 1 x 16 antenna

Fig. 3 (a) and (b) are the directional diagrams of planes E and H of the antenna. The half power lobe width of plane E is 6°. The sidelobe level is -15.1dB. The half power lobe width of plane H is 70°.



(a) (b)

Fig 3. Directional diagram of plane E and H of the antenna

The antenna array was composed of a 1 x 16 antenna, a 3-channel transmitter, and a 4-channel receptor. As shown in Fig. 4, the receptor array was on the left side, and the spacing is λ/2. The two antennas at both ends realized coupling and transceiver isolation. The three-channel transmission antennas

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were placed on the right side. In order to realize three-dimensional (3D) spatial resolution, the middle antenna was offset upward by λ/2. Transmitting antennas are available in two modes, i.e. whether one decides to use the antenna in the middle of the array.

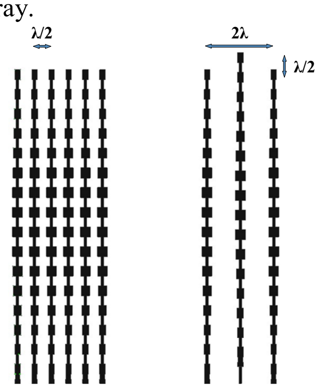


Fig 4. Layout of the antenna array

B. *RF transceiver circuit*

The RF transceiver circuit is built with the TI-manufactured AWR1443 highly integrated FMCW RF transceiver chip. The AWR1443 device is an integrated single-chip FMCW radar sensor capable of operation in the 76- to 81-GHz band. The device is built with Texas Instruments' low-power 45-nm RFCMOS process with an integrated ARM R4F processor and a hardware accelerator for radar data processing, and this solution enables unprecedented levels of integration in an extremely small form factor [6]. AWR1443 is an ideal solution for low-power, self-monitored, ultra-accurate radar systems in the automotive space.

The AWR1443 device is a self-contained FMCW radar sensor single-chip solution that simplifies the implementation of Automotive Radar sensors in the band of 76 to 81 GHz. It enables a monolithic implementation of a 3-channel transmitter, 4-channel receptor system with built-in phase-locked loop (PLL) and analog to digital converters. Simple programming model changes can enable a wide variety of sensor implementation with the possibility of dynamic reconfiguration for implementing a multimode sensor. Additionally, the device is provided as a complete platform solution including reference hardware design, software drivers, sample configurations, API guide, and user documentation. An overview of the functional block diagram of AWR1443 is illustrated in Fig. 5.

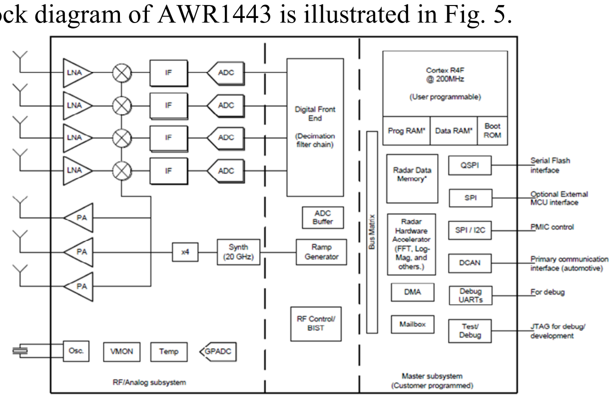


Fig 5. Block diagram of AWR1443

The power supply system was composed of LM46002-Q1 and LP87524B-Q1 produced by Texas Instruments and has four-way (3.3V, 1.2V, 1.8V, and 2.3V) output. The peripherals used were CAN and such high-speed interface as FLASH and JTAG. The transceiver circuit had a 6-layer panel structure. The layer-stack structure is as shown in Fig. 6. The second and the fifth layers were ground layers that provided a complete ground plane for the entire circuit. The other 4 layers were signal layers for laying the signal line and power line. The medium between the first and the second layers was Rogers 3003 with a dielectric constant of 3.0 and a thickness of 5 mils. The medium between other layers was FR4 with a dielectric constant of 4.2 and a thickness of 10 mils and 5mils respectively.

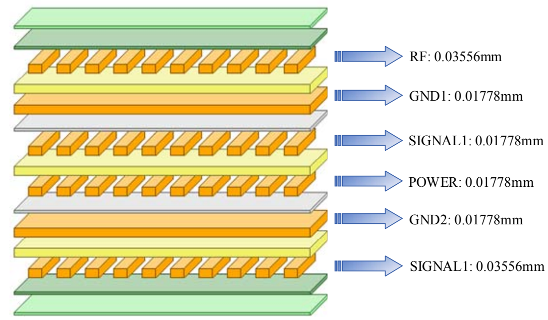


Fig 6. Layer-stack structure

The transceiver antenna was placed on the top layer with the surrounding space isolated to prevent interference. The RF transmission line was a 50 Ω impedance matching line. The final PCB domain is as shown in Fig. 7.

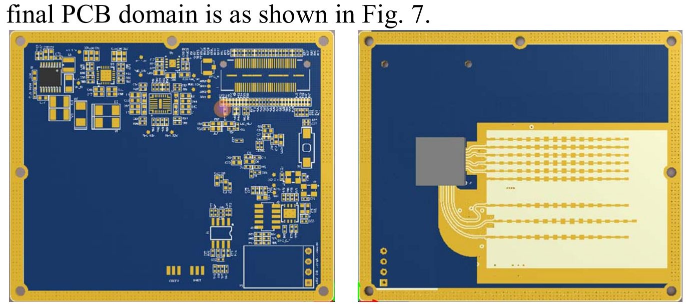


Fig 7. PCB design

III. GESTURE RECOGNITION ALGORITHM

The general process of signal processing is as follows: ADC sampling was conducted on the IF signal; then 1D FFT was carried out to obtain the distance; 2D FFT was implemented to obtain the speed; followed by the angle calculation to obtain the azimuth of the object. The flow of the complete processing is as shown in Fig. 8.

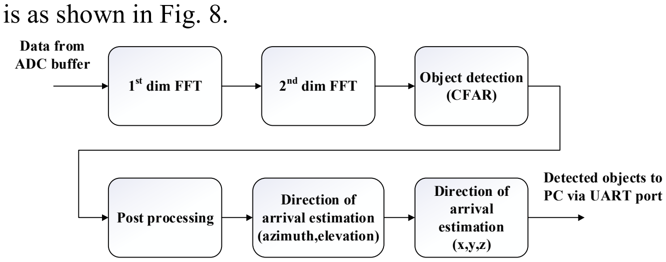


Fig 8. Signal processing process

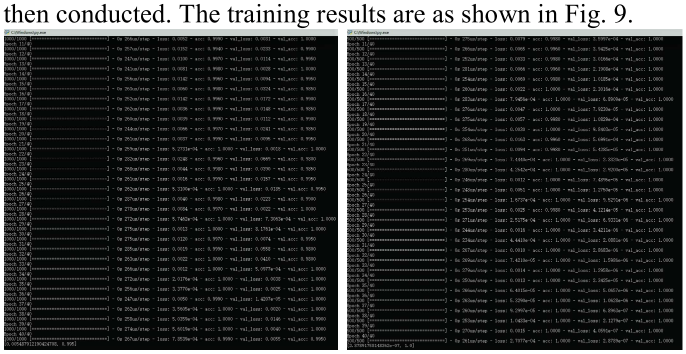
The test data was sent to the PC via “Data UART” with a baud rate of 921,600 bps. The data were transmitted in the form of data packages which were composed of the header and all the enabled data, with lengths of a 32-byte integer multiplier. A package was transmitted by each frame.

The gesture recognition algorithm was implemented with TensorFlow. In this paper a classifier with a convolutional neural network (CNN) was established to study the data sample at the front-end of the radar and train the model. Then the trained model was used for the real-time analysis of the data transmitted by the radar to realize the recognition of clockwise and counterclockwise rotations of fingers. Finally, PyQt was used to draw the volume control schematic diagram so that the magnitude of the volume could be controlled depending on the gesture.

IV. Experimental Settings and Results

The CNN was comprised of two layers: the first layer was used to judge whether the gesture is an effective action; the second layer was used to judge the rotational direction of the gesture, i.e., clockwise or counterclockwise. The two layers of neural network were trained respectively: the first layer was trained with 1,000 data sets and tested with 200 data sets; the second layer was trained with 500 data sets and tested with 100 data sets.

The instructions sent by “USER UART” set the radar and enabled two transmitting antennas. The number of points of the 1D and 2D FFT is 64. The original data before the CFAR were collected. The inter-frame space (IFS) of transmission is 80 milliseconds. The data collected were disorganized with Python to improve the applicability of the model and then rearranged into the shape of (6, 12, 1). Then deep learning was then conducted. The training results are as shown in Fig. 9.



(a) Result of layer1 (b) Result of layer2

Fig 9. Training results

The trained model parameters were stored as Python’s H5 file, through which the trained model was used to judge the feedback from the front-end of the radar. Clockwise rotation increases the corresponding volume, while counterclockwise rotation decreases the volume. Finally, the results are displayed using PyQt as shown in Fig. 10. Experimental results showed that the gesture recognition function can be realized by processing the radar data with deep learning.

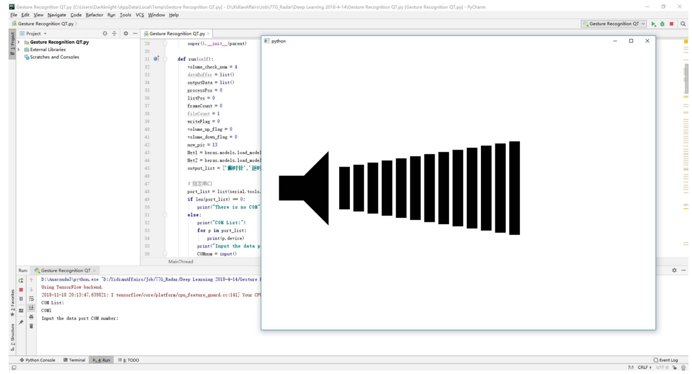


Fig 10. Volume display in PyQt

V. Conclusion

The preliminary results obtained from the development of the radar system showed the possibility of gesture recognition with an MMW radar. The limited resources of low-power consumption MCU in the system were sufficient to be used to calculate the FFT, CFAR, and other arithmetical operations, allowing it to perform simple data post-processing. However, the deep learning algorithm used in similar gesture recognition should be run in cooperation with a host computer (PC). The further development of the system may involve high-speed data interface transmission and cooperation with DSP for data processing. This will improve the accuracy of the gesture recognition, reduce the volume of the system, and complete the implementation of the whole system on the chip.

Acknowledgment

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