Research on High Speed Data Acquisition of Short Range Millimeter Wave Imaging

Guoping Chen [1], Yinlong Zhao [2, a], Menglin Wu [2, b], Benjie Zhou [1]

[1] College of Optoelectronic Engineering Chongqing University of Posts and Telecommunications Chongqing, China.

[2] College of Communication and Information Engineering Chongqing University of Posts and Telecommunications Chongqing, China.

[a] 1032281550@qq.com, [b] 136489838@qq.com

Abstract. A design scheme for millimeter-wave MIMO data acquisition and analysis system is proposed. Data collection, data storage, and data analysis were analyzed. And data can be sent via the high-speed interface (such as LVDS or CSI2) to the external processing module via Cortex-R4F control. After testing, the system can identify two objects.

Keywords: Millimeter wave imaging; Data acquisition; ADC; LVDS; CSI2.

1. Introduction

In recent years, terrorist attacks at home and abroad have increasingly threatened people's lives and property [1]. It brought an unprecedented need for a security inspection system to detect dangerous goods carried by terrorists, sometimes hidden in clothes. Active millimeter-wave safety imaging systems [2] [3] have become one of the promising countermeasures due to their high resolution and penetration capability. However, due to the high cost, the deployment of existing systems is very limited.

Millimeter wave imaging technology must have data in order to image, so data acquisition is the prerequisite for imaging. With the continuous advancement of science and technology, people are increasingly demanding data acquisition systems. Not only do they require high sampling accuracy and fast data conversion speed, they also require that the system has strong anti-interference ability and can perform real-time processing. At the same time, the application of data acquisition systems has become more and more widespread, from civil communications, medical care, detection to military radar, missiles, remote sensing, measurement and control, etc.; core components of data acquisition systems, high-speed analog-to-digital converters (Analog-to The continuous development of Digital Converters (ADCs) has prompted other related disciplines to develop toward more precise, stable, high-speed and low-power consumption, and has played a significant role in the development of science and technology and various aspects of the national economy and the people's livelihood [4] [5].

Data acquisition refers to the process of sampling and converting an analog signal into a digital signal, storing the resulting digital signal and transmitting it to a computer for calculation and display. Compared with the traditional analog system in the operation and processing of the cumbersome, complex and other shortcomings, the digital system in the performance of the analog system has unparalleled advantages, and now the digital system in the field of information engineering occupies a dominant position. Therefore, data acquisition and data analysis play an irreplaceable role in more and more fields.

High-speed data acquisition and preprocessing systems occupy a pivotal position in modern information processing systems. In modern information processing technology, most of the work is done through a digital circuit-based system to accomplish information acquisition, processing, control, and transmission. The speed and accuracy of data acquisition, and the data storage and transmission rates obtained from acquisition directly affect the performance of the entire processing system.

2. System Architecture

Millimeter wave imaging can be divided into passive millimeter wave imaging and active millimeter wave imaging according to the working mode. Passive millimeter wave imaging uses a millimeter wave radiometer to acquire the self-radiation and background scattering distribution characteristics of the measured object and generate an image. Active millimeter wave imaging emits a certain power of millimeter wave signal through the transmitter to illuminate the measured target, and uses the receiver to collect the echo signal reflected by the detected target, record its amplitude and phase information and reconstruct the spatial scattering of the measured target. Intensity image. Since the active millimeter wave imaging has a larger amount of information than the passive one, most of the practical applications are active millimeter wave imaging systems [6] [7].

According to actual needs, we use active millimeter wave imaging. In this design example, the core control of the hardware system is Cortex-R4F. The Cortex-R4F can control the sampling data buffer in the ADC Buffer or transmit the sampled data, the associated clock and the frame synchronization signal through the LVDS and CSI2 serial interfaces. Subsequent processing modules (such as DSP, FPGA) complete the imaging algorithm processing. The clock module is boosted to the required frequency by the PLL and frequency multiplier through a 40 and 50MHz crystal oscillator, and finally distributed to each module through the clock management circuit; the receiving module receives the echo signal reflected by the target through the antenna, the front-end conditioning circuit, The Σ-Δ ADC completes the sampling of the four intermediate frequency signals to complete the signal acquisition of the front end, and analyzes the received data. A schematic diagram of the data acquisition system is shown in Fig. 1.

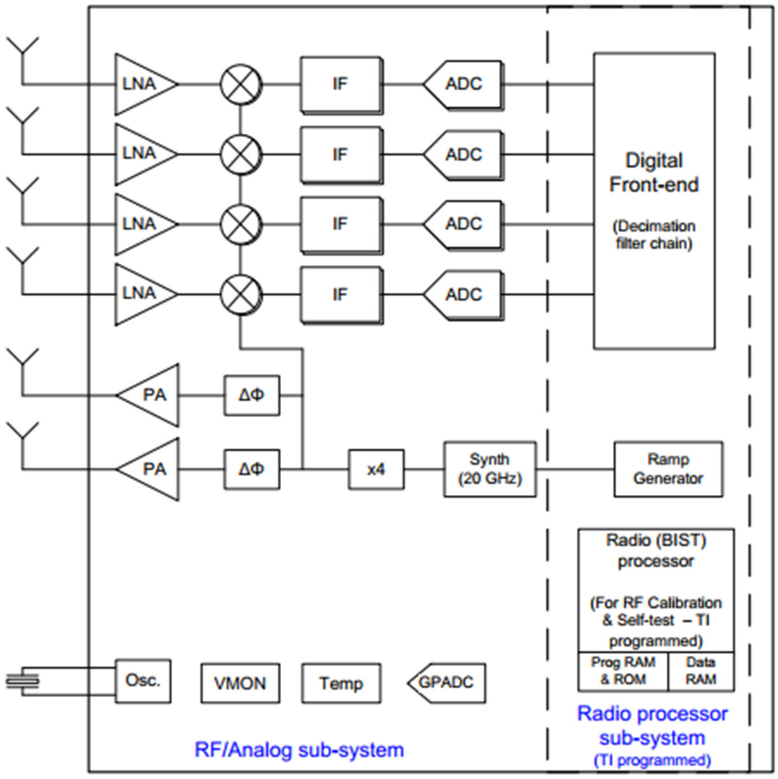

Fig. 1 System Architecture

Cortex-R4F is the core functional device of the module. The core software tasks are: (1) Using ARM-R4F to control the transmit FMCW of the transmit module, and setting the properties of the FMCW (FMCW slope, duration, TX power, etc.); (2) Set the working mode of the module to MIMO, and the flow of data; (3) Complete the correlation algorithm of digital down conversion and intermediate frequency filtering. This example is designed with the Cortex-R4F, which features architecture for safety-critical applications, floating point functionality, advanced connectivity options, flexible real-time control peripherals, and a powerful communications interface.

3. Introduce Submodules

3.1 Millimeter Wave Transmit Module

In order to achieve MIMO, the front-end antenna needs to be reasonably designed.

In order to maximize the angle of arrival θ, we can design the distance d of the receiving antenna to be λ/2, and the antenna is shown in Fig. 2.

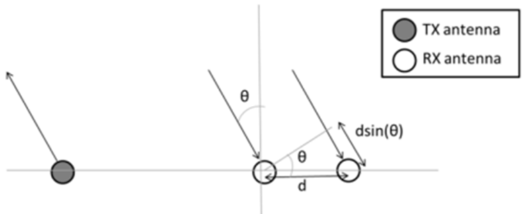

Fig. 2 Receiving antenna distance

The signal from the TX antenna is reflected from an object (at an angle θ with regard to the radar) and is received at both RX antennas. The signal from the object must travel an additional distance of dsin(θ) to reach the second RX antenna. This corresponds to a phase difference of $\omega = (2\pi / \lambda)d\sin(\theta)$ between the signals received at the two RX antennas. Therefore, when the phase difference, ω, is estimated, the angle of arrival, θ, can be computed using Equation 1.

$$\theta = \sin^{-1}(\omega\lambda/2\pi d) \tag{1}$$

Because the phase difference, ω, can be uniquely estimated only in the range (–π, π), it follows by substituting ω = π in Equation 1, that the unambiguous field of view (FOV) of the radar is as follows in Equation 2.

$$\theta_{FOV} = \pm\sin^{-1}(\lambda/2d) \tag{2}$$

Thus, the maximum FOV of Equation 3 is achieved with an interantenna distance, d = λ/2.

$$\theta_{FOV} = \pm 90^{0} \tag{3}$$

As shown in Fig.3, the transmit channel can be programmed to meet the needs. For example: set start frequency, transmit frequency slope, ADC sampling time, ADC effective start time, and so on.

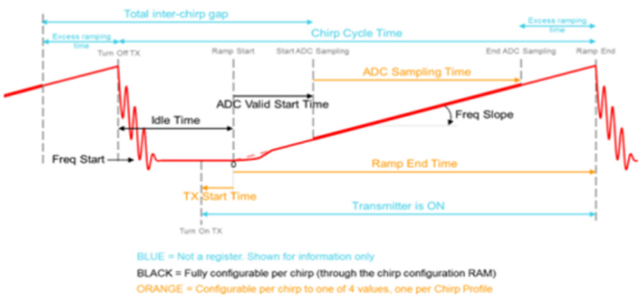

Fig. 3 chirp signal

As shown in Fig.4, the transmit channel can be programmed to meet the needs. For example: set start frequency, transmit frequency slope, ADC sampling time, ADC effective start time, and so on.

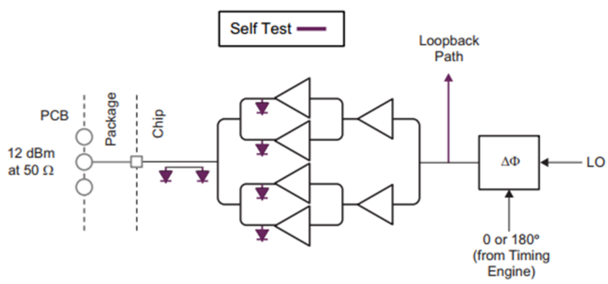

Fig. 4 Millimeter wave transmit module

3.2 Millimeter Wave Receiver Module

The receiving module consists of four parallel channels. A single receive channel consists of LNA, mixer, IF filter, and ADC, as shown in Fig. 5. All four receive channels can operate simultaneously, and separate shutdown options are also available for system optimization. The clock management provides the baseband signal for the receiving module, and the Cortex-R4F programs the module to complete the IF filtering and data flow, so that the subsequent processing module can process the data more quickly and conveniently.

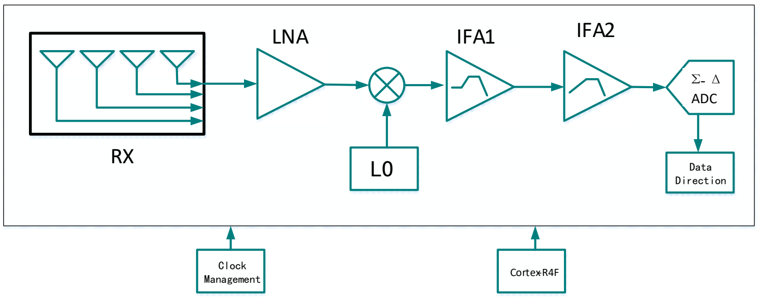

Fig. 5 Millimeter wave receiver module

Unlike conventional real-only receivers, the device supports a complex baseband architecture, which uses quadrature mixer and dual IF and ADC chains to provide complex I and Q outputs for each receiver channel. The module is targeted for fast chirp systems. The band-pass IF chain has configurable lower cutoff frequencies above 175 kHz and can support bandwidths up to 5 MHz.

3.3 Data Direction Module

The module controls the data flow of the digital front end through the Cortex-R4F, which can be programmed to control the flow of data. When the high speed interface (LVDS/CSI2) is selected, the data format and transfer rate can also be programmed to meet the needs of the interface. The schematic diagram of the module is shown in Fig. 6.

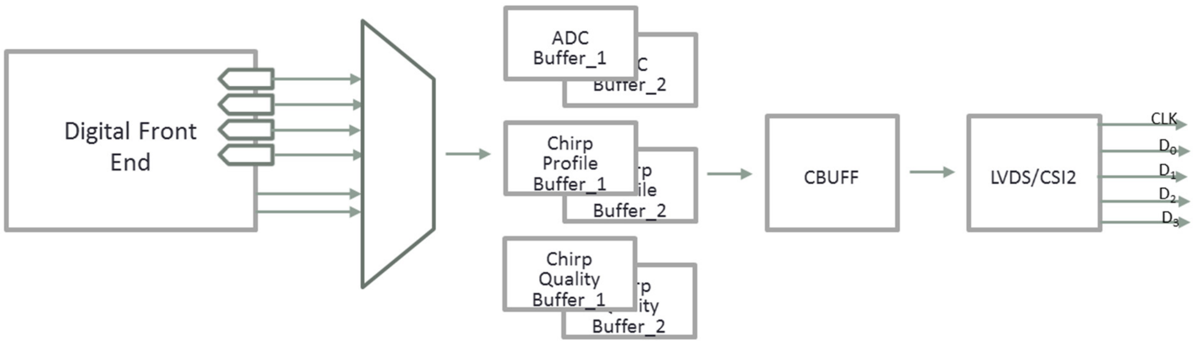

Fig. 6 Data direction

3.4 Software Design Module

There are mainly five task threads in the software design, which are in order of priority: system initialization task, radar control task, data path control task, command line interface execution task, processing DSS and MSS task. The system initialization task mainly initializes each component in the system: initialize the driver, initialize the radar module, create/start the named line interface task, etc.; the radar control task mainly generates the control task for the subsequent operation; the data path control task mainly processes the command line interface. Data path events, and start/stop completion event notification command line interface; command line interface execution tasks accept user commands and send events to process data path event control tasks; processing DSS and MSS tasks primarily handle processing received from DSS and MSS Mailbox message.

The scheduling between each thread initialization and thread task is done in the main function. The specific software flow chart is shown in Fig. 7.

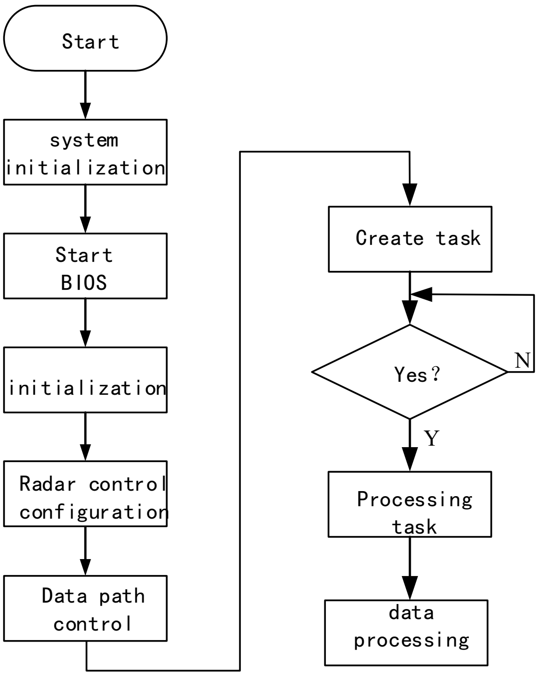

Fig. 7 Software design module

4. Test Results and Analysis

The data obtained by the above acquisition system is subjected to 1D-FFT, 2D-FFT, CFAR detection and azimuth estimation by an external DSP, and then imaged.

The data obtained by the above acquisition system is imaged on the PC side. Since the laboratory site is now only identified for targets within 0.5m wide and 0.4m long and 1m wide and 1m wide.

As shown in Fig. 8, it is a schematic diagram of the target detected by placing a target object at a distance of about 0.2 m from the acquisition module, and the right graph is a related power diagram after being processed by the DSP.

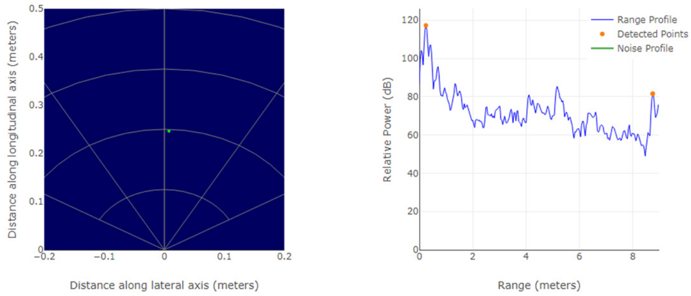

Fig. 8 Identify a target

As shown in Fig.9, it is a schematic diagram of the target detected by placing two target objects about 0.2 m away from the acquisition module.

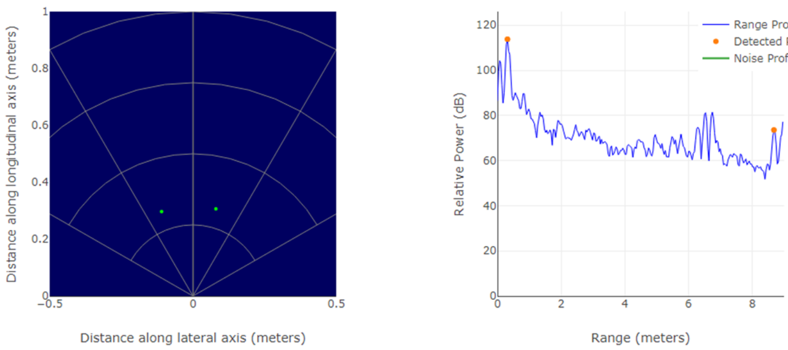

Fig. 9 Two targets were detected

As can be seen from the figure, the system design can accurately locate the target object accurately.

This plot displays the radar cube matrix for zero Doppler only but across all range bins and all antennas (see Fig. 10). For the advanced frame, this plot shows the heatmap for the first subframe, which has this plot enabled in the command (the plot title reflects this subframe number).

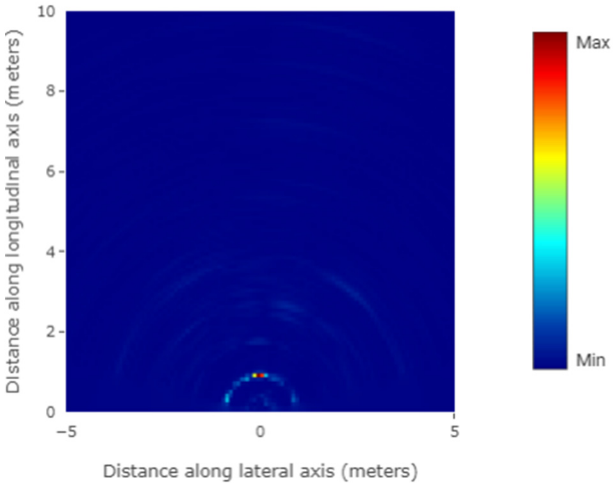

Fig. 10 Azimuth-Range Heatmap

5. Conclusion

In this paper, a Cortex-R4F control core is adopted, and a MIMO antenna is used, and a high-performance Σ-Δ AD converter is used for sampling. The working principle and method of each module are introduced in detail. After actual testing, the system can meet the design requirements, and can collect data and properly buffer it in the ADC Buffer or transmit it to the subsequent processing module through LVDS and CSI2. The system scheme has many reference values and has a high development prospect.

References

[1]. Q. Xu, A. Qing, J. Zang, et al, A point-by-point approach for fast and cost effective active millimeter-wave imaging [C]// 2017 International Applied Computational Electromagnetics Society Symposium (ACES), Suzhou, 2017: 1-2.

[2]. D. M. Sheen, D. L. McMakin, T. E. Hall. Three-Dimensional Millimeter-Wave Imaging for Concealed Weapon Detection [J]. IEEE Trans. on Microwave Theory and Technique, 2001, 49 (9): 1581-1592.

[3]. Sheen D M, Mcmakin D L, Hall T E. Cylindrical millimeter-wave imaging technique and applications [J]. 2006, 6211.

[4]. Haichao Ma. Ultra-high speed data acquisition technology development status [J], 2003, 17 (4): 287~292.

[5]. Wenfang Li, Xingxin Chen. The choice of ADC and its use should pay attention to the problem [J]. 2006, (5): 41~46.

[6]. Takhar D, Laska J N, Wakin M B, et al. A New Compressive Imaging Camera Architecture Using Optical-Domain Compression [J]. Computational Imaging IV at IS&T /SPIE Electronic Imaging. 2006: 43-52.

[7]. Appleby R, Anderton R N, Price S, et al. Whole-body 35-GHz security scanner [J]. SPIE Proceedings, 2004, 5410: 244-251.