Fuzzy Systems and Data Mining IX
A.J. Tallón-Ballesteros and R. Beltrán-Barba (Eds.)

doi:10.3233/FAIA231013

The Processing Method of Wrist Radial Artery Ultrasonic Signal Based on CORDIC Algorithm

Chaohong Zhang[a,b], Xingguang Geng[a,b] ,Jun Zhang[a,b],Yunfeng Wang[a,b] and Yitao Zhang[a,b,1]
[a] *Institute of Microelectronics of Chinese Academy of Sciences, China*
[b] *University of Chinese Academy of Sciences, China*

Abstract. The human wrist radial artery is rich in important physiological and pathological information. The rapid dynamic detection of radial artery can be realized by ultrasonic imaging method. Because of the small amplitude fluctuation and narrow vessel width of the wrist radial artery, it is difficult to detect the vessels by ultrasound. In ultrasonic nondestructive testing system, CORDIC algorithm can realize complex operation only through simple addition, subtraction and shift transformation. It has obvious advantages in high-speed operation, especially suitable for optimizing ultrasonic signal processing algorithm. Based on CORDIC algorithm, this paper proposes a phased array ultrasonic signal processing method for wrist radial artery. The dynamic filtering, orthogonal demodulation and logarithmic compression techniques using CORDIC algorithm are mainly studied. FPGA simulation results show that CORDIC algorithm can realize the rapid reproduction of the wrist radial artery ultrasonic echo signal, which lays the foundation for the next step of the interpretation of the physiological and pathological information on the radial artery.

Keywords. wrist radial artery, ultrasonic phased array, CORDIC algorithm, dynamic filtering, quadrature demodulation, logarithmic compression, FPGA simulation

1. Introduction

Traditional Chinese medicine (TCM) can judge the patient's physical state by interpreting the basic information such as pulse width and pulse length[1]. However, TCM doctor mainly interprets the information related to the wrist radial artery through finger perception, which has subjective factors and lacks objective quantitative standards. With the development of pressure sensor technology, pulse diagnosis equipment used to detect radial artery information provides a basis for the objectification of pulse diagnosis[2]. Its acquisition probe is also transformed from the original single pressure sensor probe to the array pressure sensor probe. And its detection range is gradually transformed from the original single pulse wave detection to the measurement of pulse width and pulse length. At present, most of the detection methods are passive detection.

[1] Corresponding Author, Yitao Zhang (Institute of Microelectronics of the Chinese Academy of Sciences, Beijing 100029, China; University of Chinese Academy of Sciences, Beijing 100049, China) and E-mail: zhangyitao@ime.ac.cn.

The pulse width and pulse length are estimated according to the three-dimensional topographic map of array signal, which lacks certain accuracy.

Ultrasonic phased array system, which is an important nondestructive testing method, can ensure the high precision real-time processing of data signals, so as to effectively improve the stability of the system. With the rapid development of modern IC integrated circuits, high-end FPGA chip resources are now quite rich, with sufficient high-speed I/O pin resources, and even embedded DSP hardware resources, which can provide fast signal communication processing capabilities, especially for ultrasonic phased array system design[3].

CORDIC is the abbreviation of coordinate rotation numerical calculation method. The essence is to approximate the desired rotation Angle by constantly adding and subtracting the positive and negative directions through a fixed angle [4,5]. It can make proper rotation and orientation operations without complex mathematical operations, such as trigonometric function table, multiplication, square root, and inverse trigonometric function, and reduce the difficulty of hardware implementation [6]. CORDIC algorithm has developed rapidly, and is improving towards the trend of high base, high precision and high throughput [7]. In view of its own characteristics, it is especially suitable for the practice of complex function algorithm design based on FPGA and other programmable hardware. It provides a new idea for ultrasonic signal processing and has practical significance for ultrasonic nondestructive testing technology and its development.

The structure of the paper is arranged as follows. The system architecture is briefly outlined in Section 2 firstly. In Section 3, this paper focuses on the application of CORDIC algorithm in the detection of wrist radial artery ultrasonic signals. The echo signal dynamic filtering is completed based on the radix-4 CORDIC algorithm. The digital signal envelope quadrature demodulation is completed based on the Mixed Coarse Fine Tuning CORDIC Algorithm. And based on the improved SF-CORDIC algorithm, the logarithmic compression of the signal is completed. Finally, the preprocessing of radial artery ultrasound signal is realized. and the performance of the algorithm is simulated on FPGA. Then, FPGA simulation results are displayed in Section 4. Finally, in Section 5, we draw the conclusions that CORDIC algorithm can realize the rapid reproduction of the ultrasonic echo signal of the radial artery, laying the foundation for the next step of the interpretation of the physiological and pathological information of the radial artery.

2. System architecture

Ultrasonic phased array system, which is mainly composed of four parts, includes ultrasonic sensor, transmit-receive module, radial artery ultrasonic echo signal processing and upper computer main control module. The ultrasonic sensor is a transducer which realizes the conversion of electrical signal and acoustic signal. The transmit-receive module outputs the transmitting array element excitation signal according to the required delay, generates the corresponding sequential logic control signal when scanning the array, and receives the ultrasonic echo signal with the acquisition array. In the whole radial artery ultrasonic phased system, signal processing is the key part, which can realize dynamic filtering, orthogonal demodulation, dynamic range compression and other functions[8].The upper computer is responsible for the reconstruction and evaluation of the high-fidelity image Fig.1 shows the overall architecture of the system used to process the radial artery of the wrist. Fig.2 shows the experimental system for processing the radial artery of the wrist.

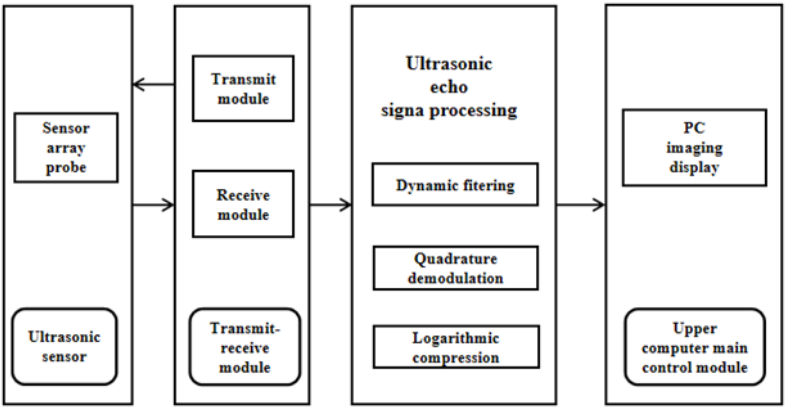

Figure 1. Overall architecture of the system used to process the radial artery of the wrist

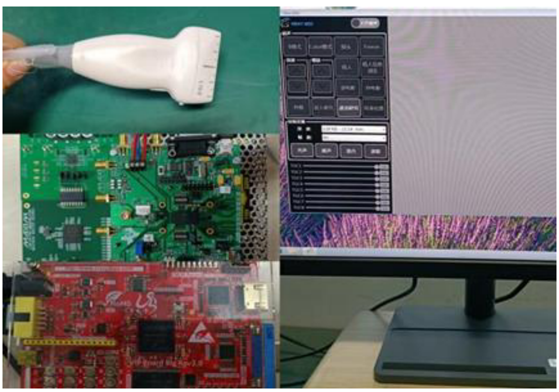

Figure 2. Experimental system for processing the radial artery of the wrist

3. Radial artery ultrasonic phased array signal processing

Radial artery ultrasonic phased array signal processing can be divided into the following modules: dynamic filtering to remove the interference and noise in the signal, orthogonal demodulation to extract the useful amplitude signal, and logarithmic compression is responsible for the dynamic range of the signal compression within 30dB.The block diagram of echo signal pre-processing system is shown in Fig.3.

3.1. Dynamic filtering based on radix-4 CORDIC algorithm

In order to solve the problem that human tissues attenuate different ultrasonic energy at different frequencies, it is necessary to dynamically filter the echo signal after beam synthesis. The implementation of dynamic filtering technology is directly related to the imaging resolution of digital ultrasonic imaging system. By dynamically receiving useful ultrasonic echo signals of different frequency bands at different depths, the near-field echo receives its high-frequency components with better resolution, and the far-field echo receives its low-frequency components to ensure the depth of detection[9].

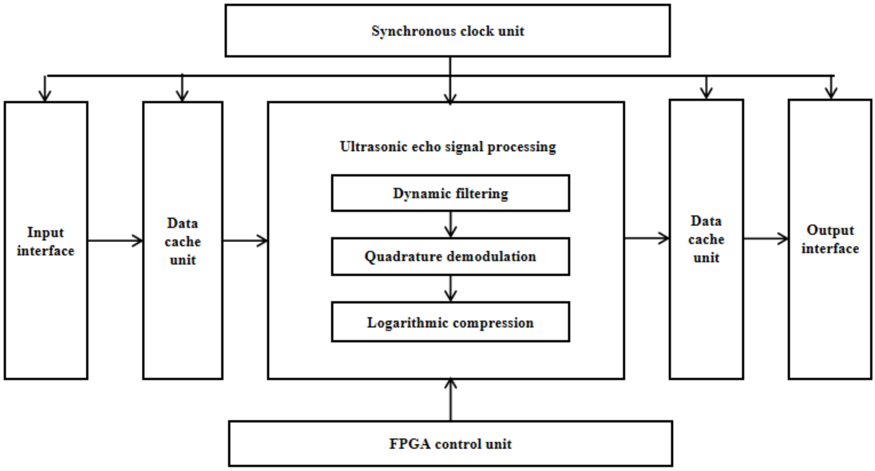

Figure 3. Logic block diagram of ultrasonic echo signal preprocessing system

In this paper, FIR filter based on distributed algorithm is used to transform multiplication into addition based on looking up RAM table, which saves multiplier resources and is faster than multiplier structure. Since the ultrasonic probe used in this paper is an 8-channel probe, and the center frequency is 3.5MHz, 64 groups of band-pass filters with order of 32 and Blackman window are used to complete dynamic filtering. To achieve the purpose of dynamic real-time calculation of filter coefficients, the radix-4 CORDIC algorithm is used[10]. Under the control of the system clock, the filter coefficients are dynamically loaded into the filter distributed RAM to achieve the purpose of dynamic filtering. The schematic diagram of dynamic filtering implemented by FPGA is shown in Fig.4.

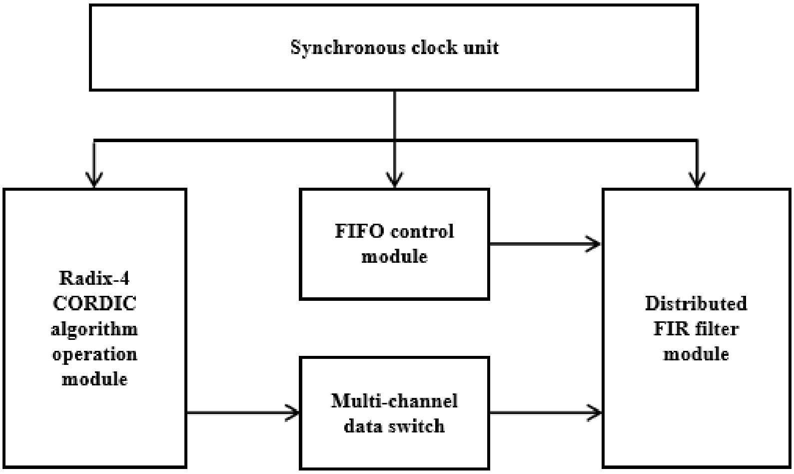

Figure 4. Schematic diagram of dynamic filtering

3.2. Quadrature demodulation based on hybrid coarse fine tuning CORDIC algorithm

In order to obtain the filtered digital signal envelope and use envelope amplitude imaging, envelope detection must be carried out[11]. The common methods of detection include low-pass filtering, Hilbert transform and quadrature demodulation. The ultrasonic echo quadrature demodulation module has excellent anti-interference performance, but it involves a large number of data operations, including square root operations, which will greatly affect the working efficiency of the ultrasonic phased array echo quadrature module.

Since the key operation of this module is square root operation, it needs to meet the requirements of operation accuracy and speed. In this paper, the mixed coarse fine-tuning CORDIC algorithm is adopted. By introducing a hierarchical pipeline, the CORDIC algorithm is divided into two levels: the input value is obtained through the rough operation module, and then as the input of the fine operation module, the final result is obtained by further calculation[12].While ensuring the calculation accuracy, both coarse and fine operations can be performed simultaneously to improve the efficiency of the algorithm and reduce the resource overhead in FPGA. Fig.5 shows the schematic diagram of CORDIC algorithm with mixed coarse fine-tuning.

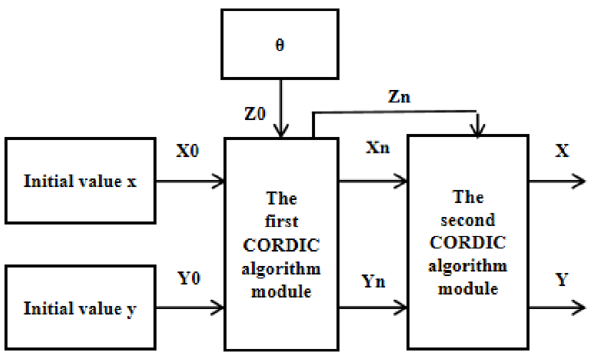

Figure 5. Schematic diagram of CORDIC algorithm with mixed coarse fine-tuning

3.3. Logarithmic compression based on improved SF-CORDIC algorithm

In this paper, an improved SF-CORDIC algorithm is used to realize logarithmic operation. By selecting the appropriate order of the McLaughlin expansion of hyperbolic sine cosine function, the algorithm completely eliminates the calculation of expansion factor and z path and does not need to do area mapping for rotation angle in advance, which greatly reduces the area cost. The figure shows the flow chart of SF CORDIC algorithm for calculating logarithmic function in vector mode, which is mainly divided into two modules: angle accumulation and iterative processing. The objective function is lnk. Initialize, x_0=k+1, y_0=k-1, z_0=0. If the i-th rotation is positive, then the i-th bit of z_1 is 1, otherwise z_2 is 1. The rotation Angle at the end of the rotation is

$$z = z_1 - z_2 \tag{1}$$

Fig.6 is shown the schematic diagram of improved SF-CORDIC algorithm implemented by FPGA in vector mode.

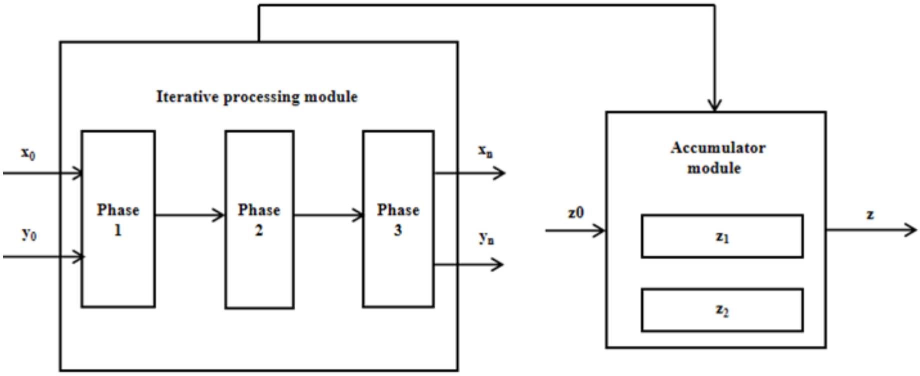

Figure 6. Schematic diagram of improved SF-CORDIC algorithm implemented by FPGA in vector mode

4. Simulation verification

In this paper, Altera's Quartus II 13.0 software is used to design the above three signal processing modules, and Mentor's ModelSim10.1d is used for simulation verification.Fig.7 is the simulation diagram of the dynamic filtering. The results show that the distributed FIR dynamic filtering can achieve better filtering effect. Fig.8 is the simulation diagram of the open square root operation of the mixed coarse fine-tuning CORDIC algorithm. It can be seen from the analysis of the waveform that both meet the design requirements.

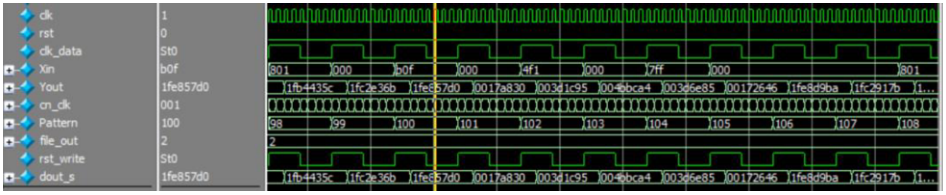

Figure 7. Simulation diagram of dynamic filtering

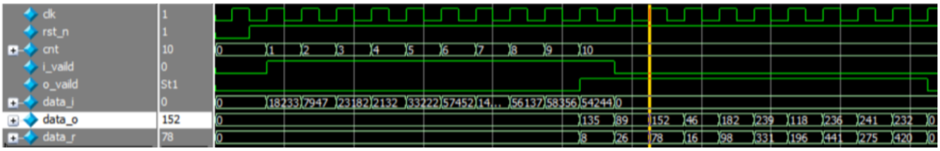

Figure8. Simulation diagram of open square root operation of mixed coarse fine-tuning CORDIC algorithm

5. Conclusion

The radial artery contains important physiological and pathological information. The ultrasonic phased array signal processing implemented by CORDIC algorithm can realize the active dynamic detection of the radial artery. In order to achieve real-time, fast and high-precision processing of radial artery ultrasonic echo signal, and reduce the design requirements of resource consumption, this paper deeply studies the application of CORDIC algorithm in the detection of wrist radial artery ultrasonic signals based on FPGA platform. In the dynamic filter module, the radix-4 CORDIC algorithm, which can effectively filter the burr, and has achieved an ideal filtering effect. Combined with the characteristics of ultrasonic echo signal quadrature demodulation and hybrid coarse fine adjustment CORDIC algorithm, the real-time signal processing is guaranteed and the hardware complexity is reduced through modeling and simulation. Finally, the improved SF-CORDIC algorithm is used to compress the dynamic range from 60dB to 30dB. CORDIC algorithm can realize the rapid reproduction of the ultrasonic echo signal of the radial artery of the wrist, and lay a foundation for the next interpretation of the physiological and pathological information of the radial artery. This paper only studies three key technologies of radial artery ultrasonic phased array signal processing module, but the applicability of CORDIC algorithm is not limited to these modules, and other improved CORDIC algorithms also need to be further studied. In the future work, the application value of the improved CORDIC algorithm in other modules of ultrasonic phased array will be studied, and to fully utilize the performance advantages of CORDIC algorithm in the field of medical ultrasound.

6. Funding and patents

Sichuan Major Science and Technology Projects (NO. 2022ZDZX0033) provides necessary financial support for data acquisition and algorithm verification.

References

[1] Lui T H, Chan S K. Endoscopic ganglionectomy of the tarsal tunnel: A medial approach[J]. Arthroscopy Techniques, 2021, 10(6): e1615-e1619.

[2] Wang S, Zhang Z, Chen Z, et al. Development of Pressure Sensor Based Wearable Pulse Detection Device for Radial Pulse Monitoring[J]. Micromachines, 2022, 13(10): 1699.

[3] Zhu K, Wen C, Aljarb A A, et al. The development of integrated circuits based on two-dimensional materials[J]. Nature Electronics, 2021, 4(11): 775-785.

[4] Shin K Y, Jeon S C, Nam K C, et al. Implementation of array sensor module for a radial artery tonometry[C]//2010 Annual International Conference of the IEEE Engineering in Medicine and Biology. IEEE, 2010: 6397-6400.

[5] Shi Z, He Q, Liu Y. Accelerating parallel Jacobi method for matrix eigenvalue computation in DOA estimation algorithm[J]. IEEE Transactions on Vehicular Technology, 2020, 69(6): 6275-6285.

[6] Zhu Z, Quan H, Tian L, et al. The Design of NCO Built in Ultra High-Speed Data Converter[C]//2020 IEEE 3rd International Conference on Electronics Technology (ICET). IEEE, 2020: 319-323.

[7] Lopez S, Vladimirova T, Gonzalez C, et al. The promise of reconfigurable computing for hyperspectral imaging onboard systems: A review and trends[J]. Proceedings of the IEEE, 2013, 101(3): 698-722.

[8] Boekhoven R W. Mechanical characterisation of healthy and diseased carotid arteries using ultrasound[J]. 2015.

[9] Gupta A K, Chowdhury V, Khandelwal N. Diagnostic radiology: recent advances and applied physics in imaging[J]. 2013.

[10] Shiri A. A Novel Implementation of CORDIC Algorithm Based on Dynamic Microrotation Generation[J]. International Journal of Electrical and Computer Sciences (IJECS), 2021, 3(1): 17-27.

[11] Wachinger C, Klein T, Navab N. The 2D analytic signal for envelope detection and feature extraction on ultrasound images[J]. Medical image analysis, 2012, 16(6): 1073-1084.

[12] Choi Y C, Yoo S S, Yoo H J. A fully digital polar transmitter using a digital-to-time converter for high data rate system[C]//2009 IEEE International Symposium on Radio-Frequency Integration Technology (RFIT). IEEE, 2009: 56-59.