Efficient Acceleration for Total Focusing Method Based on Advanced Parallel Computing in FPGA

Chong Wang
State Key Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, P. R. China.
University of Chinese Academy of Sciences, Beijing 100049, P. R. China.

Jie Mao, Tao Leng, Ze-Yu Zhuang and Xiao-Min Wang
State Key Laboratory of Acoustics, Institute of Acoustics, Chinese Academy of Sciences, Beijing 100190, P. R. China.

(Received 1 December 2016; accepted 12 June 2017)

Total focusing method (TFM) has improved resolution and accuracy over traditional ultrasonic phased array technology. In this paper, an advanced parallel architecture in field programmable gate arrays is proposed by Holmes in 2005.\(^1\) Based on the full matrix capture, the total focusing method (TFM) is an advanced phased array imaging algorithm, which was proposed by Holmes in 2005.\(^1\)

From a long time, the TFM can only be achieved offline due to the huge amount of data acquisition and computation requirements. Real-time inspection is a key aspect for ultrasonic testing in industrial fields, and many efforts have been devoted to accelerate the TFM inspection over the past years.

Parallel computing platforms, including CPU, GPU, and FPGA, are suggested to implement the TFM algorithm. Early efforts were suggested by using general purpose PC-based modules in 2012 and achieved an imaging speed at merely 20 Hz.\(^4\) Today, GPU components have an improved ability in concurrency over CPU. However, limited by the transfer bottleneck of raw data and the nature of inherent serial execution, the real-time imaging in GPU could only be achieved at low configurations and the frame rate decreases seriously when the number of elements or pixels increases.\(^5\)\(^6\)

The FPGA provides a suitable parallel characteristic and an implementation of TFM was also provided in 2013.\(^7\) However, the maximum frame rate that it can achieve is 73 Hz and decreases to less than 20 Hz in a higher configuration of 128 × 128 pixels. The efficiency is not enough as the design is far from perfect for the parallel calculation of TFM algorithm. With the flight times usually computed by software, it takes several periods for FPGA to get them serially from external memory, which extends the time to generate an imaging pixel and limits the parallelization of the process. Moreover, as a result of the serial generation of pixels in the design, the imaging efficiency decreases dramatically when the number of pixels or elements increases. A fast beamformer with time-multiplexing was provided for several beam forming lines.\(^5\) But the concurrency is sensitive to the sampling rate, which limits the fast calculation for TFM in industrial applications with a high sampling frequency normally.

Aiming to meet the need of real-time applications, this paper investigates an advanced parallel architecture in FPGA to accelerate the efficiency of TFM calculation, including the real-time concurrent time of flight calculation, parallel generation of multiple pixels, and the Hilbert transform to the pixels array. Compared to traditional designs, a higher degree of parallelization for the TFM calculation can be achieved. Experimental results on phased array system indicated that a strict real-time TFM imaging could be obtained and the high efficiency remained constant when the pixel number increased.

1. INTRODUCTION

Ultrasonic phased array testing for non-destructive evaluation has developed dramatically in recent years owing to the improved sensitivity and coverage over single element transducer.\(^1\)\(^2\) Based on the full matrix capture, the total focusing method (TFM) is an advanced phased array imaging algorithm, which was proposed by Holmes in 2005.\(^3\)

From a long time, the TFM can only be achieved offline due to the huge amount of data acquisition and computation requirements. Real-time inspection is a key aspect for ultrasonic testing in industrial fields, and many efforts have been devoted to accelerate the TFM inspection over the past years.

Parallel computing platforms, including CPU, GPU, and FPGA, are suggested to implement the TFM algorithm. Early efforts were suggested by using general purpose PC-based modules in 2012 and achieved an imaging speed at merely 20 Hz.\(^4\) Today, GPU components have an improved ability in concurrency over CPU. However, limited by the transfer bottleneck of raw data and the nature of inherent serial execution, the real-time imaging in GPU could only be achieved at low configurations and the frame rate decreases seriously when the number of elements or pixels increases.\(^5\)\(^6\)

The FPGA provides a suitable parallel characteristic and an implementation of TFM was also provided in 2013.\(^7\) However, the maximum frame rate that it can achieve is 73 Hz and decreases to less than 20 Hz in a higher configuration of 128 × 128 pixels. The efficiency is not enough as the design is far from perfect for the parallel calculation of TFM algorithm. With the flight times usually computed by software, it takes several periods for FPGA to get them serially from external memory, which extends the time to generate an imaging pixel and limits the parallelization of the process. Moreover, as a result of the serial generation of pixels in the design, the imaging efficiency decreases dramatically when the number of pixels or elements increases. A fast beamformer with time-multiplexing was provided for several beam forming lines.\(^5\) But the concurrency is sensitive to the sampling rate, which limits the fast calculation for TFM in industrial applications with a high sampling frequency normally.

Aiming to meet the need of real-time applications, this paper investigates an advanced parallel architecture in FPGA to accelerate the efficiency of TFM calculation, including the real-time concurrent time of flight calculation, parallel generation of multiple pixels, and the Hilbert transform to the pixels array. Compared to traditional designs, a higher degree of parallelization for the TFM calculation can be achieved. Experimental results on phased array system indicated that a strict real-time TFM imaging could be obtained and the high efficiency remained constant when the pixel number increased.

2. PARALLEL COMPUTING ARCHITECTURE FOR TFM

2.1. TFM Algorithm

Figure 1 shows the concept view of the TFM algorithm. The algorithm meshes the region of interest in a grid of pixels. A pixel is generated by summation of data from all the transmission-reception pairs.\(^3\)

The intensity \(I\) of a pixel \(P(x, z)\) is expressed by the Eq. (1).

\[
I\left[P(x, z)\right] = \sum_{j=1}^{N} h_{ij} (T_{ip} + T_{pj})
\]

(1)