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Design and Implementation of Real-time Acoustic Imaging System Using Synthetic Transmit Aperture

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1. Introduction

Recently, there are needs of using acoustic imaging system in real-time practical applications, especially in situations that cameras cannot perform imaging tasks reliably, for instance, in a dark area, in an area covered with fog or smoke. Many acoustic imaging techniques have been proposed so far. However, most of them are computational burden. They need some minutes to process all received acoustic signals.

Fast computation speed is the most important requirement for real-time applications. Although, there are some existing researches that address on real-time image reconstruction of acoustic imaging, they focus on very large scale systems, that is to say, they use hundreds of Field Programmable Gate Array (FPGA) along with a complicated network infrastructure to link between those computing units.

In this paper, we propose a real-time acoustic imaging system on a standalone FPGA where all control and signal processing tasks are performed. The output of the proposed system is aimed to be adapted to some practical applications such as surveillance systems, security systems by applying object tracking, and machine learning techniques to the obtained acoustic images.

2. System architecture

The prototype system mainly includes 3 parts: a transmission unit, a receiver circuit, and a signal processing circuit. The transmission unit is composed of a Pioneer A-D1 amplifier connected to 2 Pioneer PT-R4 transmitters. The receiver circuit is a sensor array containing 16 ultrasonic sensors with 5.08 mm. interval. Each sensors is connected to a 1-channel, 12-bit A/D converters for digitization of signals. The signal processing circuit is composed of a Xilinx Spartan-3 XC3S1000 FPGA for signal processing, and an external 256Mb SDRAM for storing large amount of referenced values. The system architecture is shown in **Fig. 1**

Inside the FPGA, the implementation is mainly divided into 2 parts, namely the embedded controller, and Digital Signal Processing (DSP) module. The computationally intensive tasks are implemented in DSP module using Hardware Description Language (VHDL and Verilog) to achieve fastest computation speed, while the command, control, debug tasks and tasks that perform only once at start-up are coded in C language in an embedded MicroBlaze soft processor [1].

We utilize Xilinx IP cores [2] and bus architectures in many parts of our design to simplify the overall system. The IP cores used in the prototype system includes MicroBlaze, BRAM Block, LMB BRAM Controller, Multi Port Memory controller (MPMC), Clock Generator, Processor System Reset Module, XPS UART Lite, XPS Interrupt Controller, MicroBlaze Debug Module (MDM), and XPS General purpose IO (GPIO). The bus architectures used in the design are Processor Local Bus (PLB) as the main bus interface, Local Memory Bus (LMB) for reading/writing instruction memory and data memory located in BRAM Block, Fast Simplex Link (FSL) for communication between the MicroBlaze and DSP module, and Native Port Interface (NPI) for reading referenced data from the SDRAM into DSP module without controlling from the MicroBlaze. The design of the system can be seen in **Fig. 2**

The DSP module is designed for very specific signal processing functions in order to optimize both running time and dedicated resources.

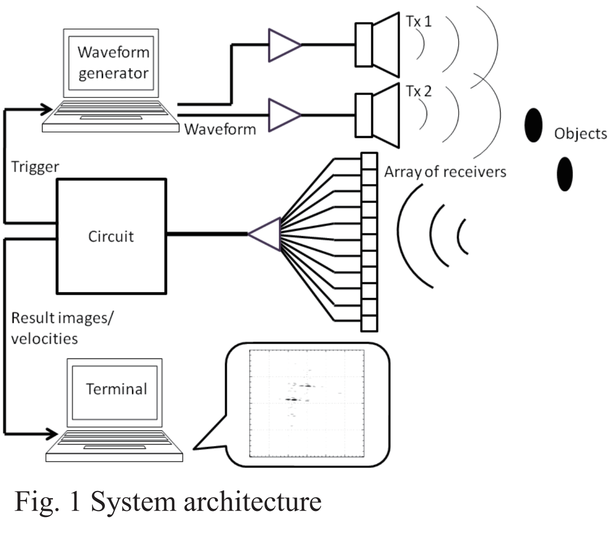

Fig. 1 System architecture

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3. Image reconstruction using synthetic transmit aperture approach

We apply the concept of synthetic transmit aperture (STA) [3] to our proposed system. The overall concept of STA is shown in **Fig. 3**. All processes in STA are designed to be implemented in the DSP module. As we can see from Fig. 3, pre-defined signals are transmitted, scattered and received by the array of receivers. After converted into digital signals, the received signals from all receivers are independently transformed into the frequency domain and fed into matched filters. Thus, these processes can be implemented in the DSP module to process the individual signal from each receiver in parallel.

The beamforming process is considered to be the critical path of the system since it is the bottleneck of STA imaging. As a consequence, the maximum possible frame rate can be determined by this critical path. Fetching pre-calculated weight values from the SDRAM takes many clock cycles but it can be disregarded in the maximum frame rate calculation if the pipeline architecture is employed.

All referenced values such as referenced waveform for conducting DFT and matched filtering, weights for beamforming, are pre-calculated in the MicroBlaze at system start-up and stored at pre-defined addresses in the SDRAM. The DSP module can directly use those values by reading at specific addresses from the SDRAM.

4. Implementation

The implementation in the MicroBlaze, buses and other IP cores is almost completed. The DSP module is now being implemented.

The timing requirement for implementing the real-time acoustic imaging system can be roughly derived from the minimum acceptable frame rate for real-time applications such as object tracking. For instance, regarding real-time human tracking application, assume that the fastest speed that human can move is 10 m/s and also presume that acceptable input error of the measurement for the tracking system is 1 m. Then, minimum acceptable frame rate is 10 frames per second. Since the prototype system works with 48 MHz system clock, this infers that the beamforming process which is the critical path of the system has to use the running time less than 480,000 clock cycles.

5. Conclusion and future work

In this paper, we have presented the design of the proposed real-time acoustic imaging system developed in an FPGA. We try to get the most out of available resources in the FPGA and available IP cores to make the system speed satisfactory for real-time applications.

In the future, we plan to improve quality of obtained images by reducing both auto-correlation and cross-correlation noises in STA imaging. We also intend to develop some applications making use of the real-time acoustic imaging system.

References

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3. J. A. Jensen, S. I. Nikolov, K. L. Gammelmark, and M. H. Pedersen: Ultrasonics 44 (2006) e5-d15

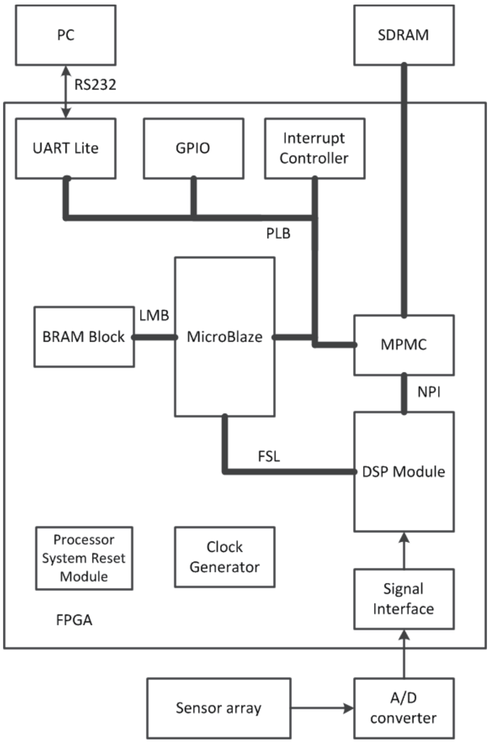

Fig. 2 System design

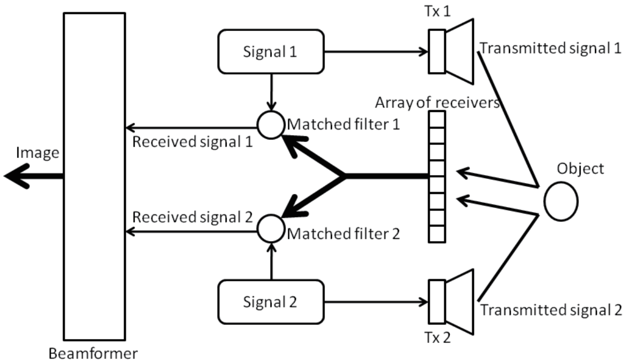

Fig. 3 Synthetic transmit aperture imaging