# RESEARCH COLLECTION ON
# ULTRASOUND VOL. 2

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Chapters from books edited by: **Masayuki Tanabe, Oleg Minin** and **G P P Gunarathne**

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# Contents

# Preface

This is the second of two volumes on the subject of ultrasound.

Since the Seventies, ultrasound imaging has been a vital diagnostic tool in hospitals and other clinical settings. It has many advantages over other techniques in terms of non-invasiveness, safety and economy and recently there have been major advances such as improvements to resolution/image quality and portability of equipment, which are increasing the scope of ultrasound still further, and enabling it to be used at point of care locations such as doctors' offices.

These books provide an extensive overview of the recent advances and current clinical applications of ultrasonography, including imaging of the breast, prostate, lungs, liver and ovaries. Topics covered include the development/application of 3D ultrasound, speckle noise reduction, ultrafast ultrasound imaging, contrast-enhanced ultrasound, Doppler ultrasound, intravascular ultrasound and the application of ultrasound during anesthesia, fetal monitoring and radiation therapy.

We believe that these books will provide essential insights into the latest techniques and applications for clinicians and imaging technicians, as well as hopefully providing the stimulus for further research.

# ULTRASOUND IMAGING

Edited by **Masayuki Tanabe**

# Hardware-Software Partitioning of Digital Signal Processing in Ultrasound Medical Devices a Case Study

Marcin Lewandowski
*Institute of Fundamental Technological Research, Polish Academy of Sciences*
*Pawinskiego 5B, 02-106 Warsaw,*
*Poland*

## 1. Introduction

The development of ultrasound devices and diagnostic methods is closely related with the development of microelectronics and digital signal processing. In most of the state of the art electronic devices, the signal is digitally processed. These devices may be generally categorized based on the number of parallel processing channels. Imaging devices with multi-element linear or phased arrays usually have 16-256 transmission/reception channels. Single channel processing is usually performed in imaging devices with mechanically moved single element sector heads, the so-called "wobbler" and in dedicated Doppler devices. The methods of signal processing are much the same in all device categories.

The paper presents a general overview of ultrasound signal processing and its digital implementation with emphasis on hardware-software partitioning. The available state of the art methods and systems of digital signal processing using both hardware and software are presented as well as the issues pertaining to algorithm implementation methodology. The state of the art system solutions are presented based on the descriptions of representative ultrasound devices, found in literature. The similarities between the presented devices and radio signal processing systems used in telecommunication are also discussed in the paper. Based on device description, the authors present the architecture of processing and communication as well as specific design solutions. The discussed issues and system solutions are analyzed based on two ultrasound medical devices, namely:

- ***uScan*** - high frequency ultrasonograph with coded transmission (Lewandowski & Nowicki, 2008),
- ***digiTDS*** - transcranial Doppler system (Lewandowski et al., 2009).

Both devices have been designed and built by the author and co-workers at the Institute of Fundamental Technological Research, Polish Academy of Sciences. They have been designed for commercial purposes, in conformity with medical standards and economic limitations.

The analysis of the presented solution comprises:

- description of the presented systems architecture and of the processing algorithm implementation,
- decisions concerning the design and hardware-software partitioning.

## 2. Digital signal processing of the ultrasound echoes

Diagnostic medical ultrasound devices utilize ultrasound waves at the frequency of 1-15 MHz. The transmitted ultrasound wave, mainly in the form of a train of short pulses, propagates in the tissue where the structures are reflected and returned to the head as echoes. The signal of echoes is initially amplified and filtered in an analogue chain and next, digitally processed using ADC (Analog-Digital Converter) with 8-14 bit of resolution (Thomenius, 2006). The received high frequency signal (called RF - radio frequency) of the echoes is amplitude- and phase modulated carrier frequency signal. The signal is demodulated in the device to obtain baseband frequency. The demodulated echo signal is further processed, depending on the application (Ali et al., 2008).

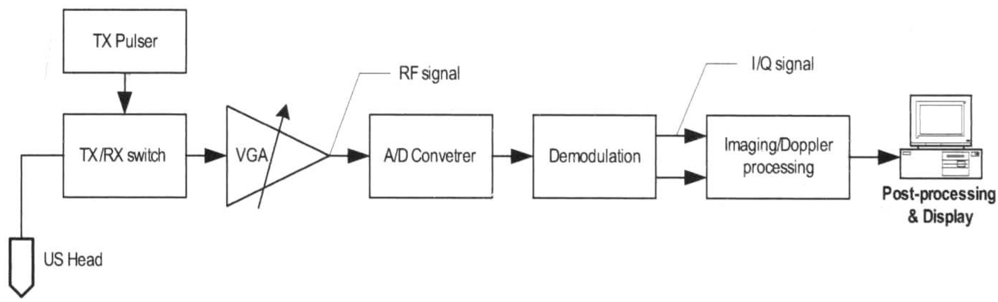


Fig. 1. Simplified block diagram of an ultrasound diagnostic device

The chain of ultrasound signal processing (Fig. 1) is much the same as the chain used in digital telecommunication. Therefore, in both cases, similar system solutions and processing methods are applied. For adaptation to quickly changing processing algorithms used in telecommunication, the Software-Defined Radio (SDR) was developed, in which RF signals are processed using software (Reed, 2002).

The generic architecture of SDR systems composed of GPP (General Purpose Processor), DSP (Digital Signal Processor), FPGA (Field Programmable Gate Array) and high frequency front-end blocks was proposed by (Bassam et al., 2009). According to the authors, universal systems of RF signal processing can be implemented based on this architecture.

The most popular example of an SDR platform is the GNU Radio project, and the compatible Universal Software Radio Peripheral (USRP) module, designed by a group of enthusiasts, later used in multiple designs and studies. The USRP module consists of a set of broadband ADC and DAC connected to the FPGA, which in turn communicates with the PC via USB interface. The board is prepared to host analogue transmitter and receiver modules, which tailor the solution to specific applications. The FPGA is responsible for signal modulation and demodulation and stream data to and from PC. The developed digital signal processing in C language with interface to Python script language enables quick and easy prototyping of radio signal processing algorithms. With its universal design and availability of a relatively cheap hardware module, the system is quite popular. The project website (http://gnuradio.org) contains information on the application of the project, as well as protocols and telecommunication standards including WiFi, RFID, DVB, DAB, GSM and DECT.

The newer and more advanced version of SDR platform named SORA was developed by Microsoft® Research. It has a significantly larger FPGA (Xilinx Virtex 5) chip and a faster

PCI-e x8 interface. Moreover, a software stack for multicore processors containing drivers and processing libraries, optimized for efficiency and latency minimization was developed (Tan et al., 2009). The authors also presented a demonstrative implementation of SoftWiFi supporting the 802.11a/b/g communication protocol.
The reader will probably notice a very high similarity between the USRP solution and coder-digitizer module of the ***uScan*** system described later in the paper. It definitely indicates a similarity between the system solutions and the architecture of SDR and ultrasound devices. Interestingly, the author has not found any report on using SDR solutions for ultrasound RF signal processing.

## 3. Digital signal processing systems

Nowadays, there is a vast number and diversity of digital signal processing systems and methods. Therefore, it is extremely difficult to select an optimal system solution for signal processing of suitable processing power, data throughput and power consumption at a reasonable price. If we limit our choice to the solutions commonly applied in ultrasonography, these will include:

- hardware processing - programmable logic systems (FPGA) and ASIC (Application Specific Integrated Circuits),
- software processing - general purpose processors (GPP), digital signal processors (DSP) and graphic processors (GPU).

Recently there is a tendency to increase software processing because of the development of processor systems and significantly easier implementation process and algorithm debugging as compared to hardware implementations. This tendency has resulted in the development of ultrasound medical devices, requiring a more efficient digital processing and working in a real time regime.
The main advantage of software solutions is easy code modification and simpler testing and debugging methods. Implementations in high level languages (e.g. C language) can be easily simulated and verified on different platforms before being implemented on the target platform. Nowadays, the majority of DSP are programmed in C language and have more advanced tools for development. Thanks to their computing power, easy high-level code development, DSP are the core of processing chain in modern devices. There is an alternative trend in software processing, namely general purpose processors (GPP). Modern PC processors have high computing power and special parallel executive units for multimedia processing. These units are in fact separate vector processors, optimized for digital signal processing. Adequate use of parallel processing and multimedia units can replace several DSP working at the same time. As PCs are frequently part of these devices and are used both as controller and user interface, the implementation of processing algorithms using PC seems natural. Real time application of operational systems, such as Microsoft® Windows is problematic as these are not real time systems and therefore they do not guarantee adequate time precision and the required operations being performed in the required time period.
Recently, graphic processor units (GPU) are used for signal processing; they are traditionally used for 3D graphics rendering in PCs. The quick development of computer graphics resulted in the development of graphic processors with new capabilities. From specialized 3D processors, GPU have been developed into versatile programmable vector processors. Thanks to its massive parallel internal architecture and advanced memory