REAL-TIME REGISTRATION OF RAW MEDICAL ULTRASOUND MULTI-MODALITY DATA USING SPECIALIZED USB DEVICE

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Abstract: Research in the field of ultrasound signal and image processing requires availability of clinical images, echocardiograms and sonograms. There are several methods how the data can be obtained for further processing in PC using commercially available ultrasound scanner. This paper summarizes advantages and disadvantages of each method. It also shows proposal of specialized USB device for real-time transfer of raw multi-modality data between ultrasound scanner and PC. It is possible to record, process and display data in the MATLAB and Simulink by special functions and blocks in real-time. Resulting images are not affected by additional noise and do not contain redundant information as it is common when capturing video signal.

Introduction

Research in the field of ultrasound signal and image processing requires availability of clinical data in the form of raw signals as well as images, echocardiograms and sonograms. There are several methods how the data can be obtained using commercially available ultrasound scanner (US), giving more or less suitable results for particular purposes:

- radiofrequency (RF) signal sampling
- envelope sampling
- video signal sampling
- using DICOM
- using mass storage
- using video tape recorder

This paper summarizes advantages and disadvantages of the above mentioned solutions first, then brings proposal of specialized USB device for real-time transfer of raw multi-modality data between US and PC. It also shows details and results of its practical realization.

Each method will be explained using basic block diagram of the US signal processing chain, see Figure 1. Scanner architecture conforms to the multi-modality of such device. There are several types of data obtained by scanner:

- B-mode images
- D (Doppler) mode sonograms (i.e. spectrograms)
- CFM (Color Flow Mapping) images
- M-mode images (tissue motion)
- supplementary ECG

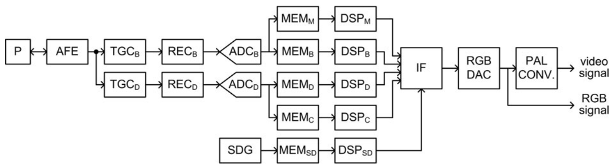

Figure 1: Ultrasound scanner signal processing chain, model with analog beamformer (P. . . probe, AFE. . . analog front-end, TGC. . . time-gain compensation, REC. . . receiver, ADC. . . analog-to-digital converter, MEM. . . memory, DSP. . . digital signal processing, SDG. . . supplementary data generator, IF. . . image formation).

There are also two different scanner architectures. Older and less accurate scanners employ fully analog beamformer, modern scanners use digital beamformer and provides better resolution and lower noise. First case will be discussed now, later some differences valid for second case will be revealed.

US signal processing chain consists of four main processing channels, B mode, M mode, D mode and CFM mode data processing channel. Fifth channel introduce supplementary data into the resulting image. They include patient record, examination notes, scales, various parts of user interface and ECG record (in the case of echocardiogram). Usually, there are two signal sources for these channels. Image processing part (B, M mode) and blood flow measurement (D, CFM mode) related part are equipped with own TGC, receiver and analog-to-digital converter. This is mainly due to different amplification and filtering, as well as different required dynamic range of ADCs. Digital processing (DSP) of image related signal includes interpolation, filtering, averaging and gray-scale coding and adjustment. D and CMF mode data are usually filtered, restricted to area of interest (i.e. sample volume), and processed with FFT to reveal spectrogram (showing distribution of blood flow velocities), in the case of color flow map coded into color scale.

Using all types of processed data, image is then formed by overlaying them and converted into video signal or similar type of signal useful for displaying or recording. Each block of architecture can be realized by means of hardware and software, including embedded computer systems, FPGAs and digital signal processors.

More detailed description of the ultrasound scanner signal processing chain using the above mentioned basic block diagram can be found in [1].

Materials and Methods

RF signal sampling is the most expensive technique, using PC equipped with high speed analog data acquisition card. Such card should allow digital triggering and is connected before receiver. Sampling RF signal before time-gain compensation (TGC) requires better dynamic range of the acquisition card. Demodulation of the sampled signal and its further processing in PC is time-consuming and demands high computing power, especially in the case when harmonic imaging is performed. Usually, signal is oversampled and sampling frequencies as high as 50 MHz are used. Displaying resulting images in real-time also brings additional costs.

Envelope sampling is very useful when only resulting images, echocardiograms and spectrograms are required. In the case of images, sampling rate is proportional to the number of obtained pixels and frame rate. For the highest frame rates (30 fps) used in clinical ultrasonography, sampling frequency will be maximally 10 MHz. When there is no need to capture all frames, it can be significantly lower. Sampling frequencies for M-mode and D-mode are in the order of kilohertz. The envelope is sampled on the output of receiver (REC).

Using DICOM, mass storage (e.g. ZIP or CD-ROM) or video signal sampling (direct or with use of video tape recorder) has several disadvantages:

- original raw image samples cannot be obtained due to additional DSP (interpolation, averaging, grayscale modifications etc.)
- original Doppler signal cannot be obtained, thus spectrogram or CFM image cannot be calculated by different method
- during CFM, overlaying B-mode and flow images cannot be reconstructed
- ECG record cannot be obtained from images
- usually only static images or short loops can be recorded to scanner internal memory and then transferred to mass storage media or through DICOM
- all images incorporate useless supplementary data (they can even occupy one half of the image area)
- scanners are rarely equipped with DICOM module

Moreover, in the case of video signal sampling, resulting images are distorted due to extra digital-to-analog and analog-to-digital conversion by introducing quantization noise and due to induced noise. Another distortion is caused by unequal frame rate of ultrasound scanner and capturing device. Scanner frame rate vary with different ultrasound probes, due to changes in region of interest and imaging modes. Often, multimedia video capture card without trigger inputs are used, which makes capturing of correctly synchronized images impossible.

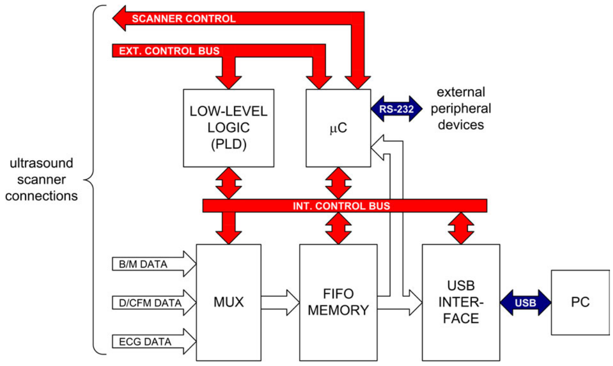

Figure 2: Block diagram of the proposed device.

Video signal sampling and mass storage media are frequently used as an image source for research, e.g. in the area of image processing and recognition. The above mentioned disadvantages of such methods make them unusable as an source of valuable data. Unfortunately, they are often used in this manner. Image processing methods developed using these sources have half of their possible value, as they are not suitable to be incorporated into US. Final product of the US signal processing chain is not intended as source for additional processing. Therefore, every potentially successful method must have raw images or signals on its input. For example, raw images are more useful for image recognition methods than final interpolated ones, because of interpolation increases amount of data (as well as noise) and brings problems with triangular region of interest (if sector probe is utilized).

Our aim is to present less known approach to envelope sampling, which uses output of scanner internal ADC (or ADCs) and specialized USB device to transfer obtained raw data samples. Therefore, it provides uninterpolated images and raw Doppler signal. Figure 2 shows block diagram of the proposed device. It was designed to meet several conditions:

- simultaneous transfer of multi-modality data
- real-time transfer and display of data in personal computer
- device should be able to set display modes and control other scanner settings
- maximal versatility of the device should allow to use it with several US models

Proposed device is connected to ultrasound scanner using its internal control signals for transfer control. Important control signals slightly differ with scanner model, but has the same meaning:

- imaging mode selection
- frame begin/frame end
- line begin/line end
- data validity

In a large digital system such as ultrasound scanner is,

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ADC is connected to other circuits through bus and using data latch. Attaching additional circuitry to a built-in latch or using external latch will reduce increase of capacity load on the output of ADC.

Need of extremely fast microcontroller is eliminated by using programmable logic devices (PLD) for low-level logic operations on control bus. Three main data buses (B/M, D/CFM, ECG) are alternately connected to FIFO through input multiplexer (MUX) owing to scanner control signals and device mode set by microcontroller.

MUX is needed for consecutive transfer of diverse data types, which is realized during one transfer session. For example, echocardiogram is transferred as consecutive blocks of M-mode data and ECG data. This is permitted by relatively large break between consecutive image frames and lines (in all imaging modes). Therefore all three types of data can be succesfully transferred during session.

Often there are differences between bus sizes; B mode signal is sampled with 8, 10 or 12-bit ADC, however D mode signal is usually sampled with 16-bit ADC. Hence, input multiplexer must deal with this problem by reduction or expansion of bus size according to the size of the bus on the output of the device. In our case, 16-bit D/CFM mode or ECG words are divided into two 8-bit bytes and transferred consecutively. The transfer is controlled by low-level logic. Another solution is to use FIFO with user-selectable input and output bus sizing (e.g. 16×8, 8×16).

Through usage of FIFO memory, time breaks between consecutive image frames and lines are utilized to decrease required transfer speed of USB interface; in other words to fully utilize its transfer speed.

According to the type of USB interface, FIFO memory can be omitted if it is incorporated in such an interface. In most cases internal FIFO memories of the USB interfaces are very small, therefore stand-alone FIFO must be used. In order to simplify the whole design, FT245BM USB FIFO was employed in combination with another stand-alone FIFO. FT245BM (see [2] for more details) is single-chip USB to parallel interface with independent transmit/receive buffers and simple four-wire handshake interface. The entire USB protocol is handled internally and therefore this IC does not require any USB-specific firmware. Drivers for most operating systems are provided for free. Application software can directly access device buffers through USB by DLL based published API. Device is USB 2.0 compatible and its data transfer rate is up to 1 MBps.

Final realization of the proposed device introduced various methods to keep its design most flexible. FIFO memory IC was not soldered directly into the mainboard; stand-alone PCB module with FIFO was used instead. It is advantage to use FIFO memory with choice of memory organization (configurable input and output bus sizes). Independent read and write clock signals should permit simultaneous reading and writing. Our FIFO module consists of Texas Instruments SN74V2x3 FIFO, capable to store up to 128 kB. It can be easily expanded in both capacity and bus width by using more units (see [3]).

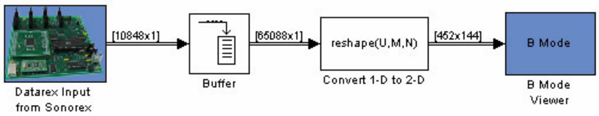

Figure 3: Simple configuration of Simulink blocks used to display raw B-mode images in real-time.

Application software for the device was realized as a MATLAB toolbox. Device can be controlled and its output obtained using MATLAB command line and M-files through toolbox M-funtions. Real-time displaying and registration of images is possible with use of specialized Simulink blocks. Blocks serve as device output and viewers for basic imaging modes. For example, the simplest useful working configuration is device output block connected to B-mode viewer (see Figure 3). S-functions are masked to provide user-friendly interface to all their settings. Device output block allows us to set scanner mode (type of transferred data) and USB transfer parameters, output FIFO timing and size of output frames.

Simulink S-functions were created using C language and compiler. Source code employs DLL library provided by manufacturer of FT245BM to control USB interface and obtain its output. S-functions are compiled as C-MEX files, a kind of DLL libraries, utilizable by Simulink. Compilation has been done using internal MATLAB MEX utility and Microsoft Visual C/C++.

Prototype of the proposed device was designed to work with ultrasound scanner SonoAce 4800HD. Figure 4 shows its final appearance.

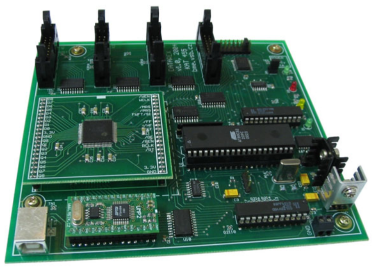

Figure 4: Final appearance of the realized USB device.

Results

The above proposed device was successfully realized and tested. Real-time imaging in B, M and A modes has been achieved using SonoAce scanner. It is possible to use both linear and convex probes. For this type of scanner, maximal frame rate of B-mode imaging was 12 fps. This speed is fully sufficient for testing a large family of image processing techniques. Figure 5 shows examples of recorded B-mode and M-mode images. This

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type of scanner uses ADC with serial output for D-mode imaging. Therefore, in case of D-mode signal sampling, proper ADC with parallel output must be employed with use of analog buffer.

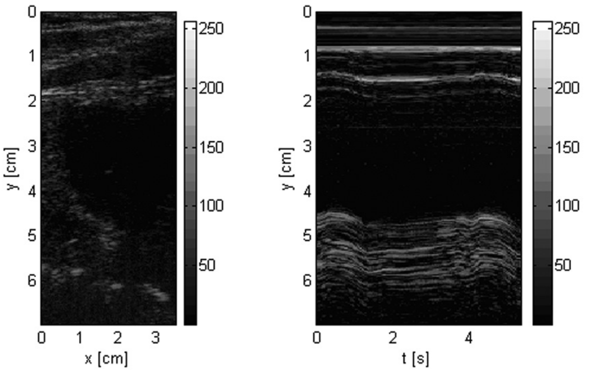

Figure 5: B-mode and M-mode images obtained in real-time and displayed with Simulink blocks.

Discussed device was intended to be used in combination with analog beamformer scanner, but is also adaptable to models with digital beamformer. Digital beamformers employ ADC in all parallel channels, digital adder and digital delay lines instead of analog ones. Device must be therefore connected behind the addear instead of ADC. However, it can be considerably harder to find appropriate point of connection.

Conclusions

This paper has shown possible methods how images and sonograms acquired by commercially available ultrasound scanner can be obtained for further processing in PC. Disadvantages of video signal sampling and mass storage media led us to propose and design specialized USB device for transfer of images and sonograms into PC. Device is useful for testing a large family of possible image processing techniques. Need of raw unprocessed images, undistorted by noise, was a main motivation during device development. Its other advantages lies in flexibility, multi-modality, real-time functionality, mobility and low costs. Device is useful for both research and educational activities in the field of ultrasound signal processing.

References

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