Systems for Research and Development in Medical Ultrasound Imaging

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The system requirements of engineers conducting research and development into new ultrasonic methods for medical applications are reported. The design criteria for these systems are explained together with a review of what is currently available.

Searching for processing advances

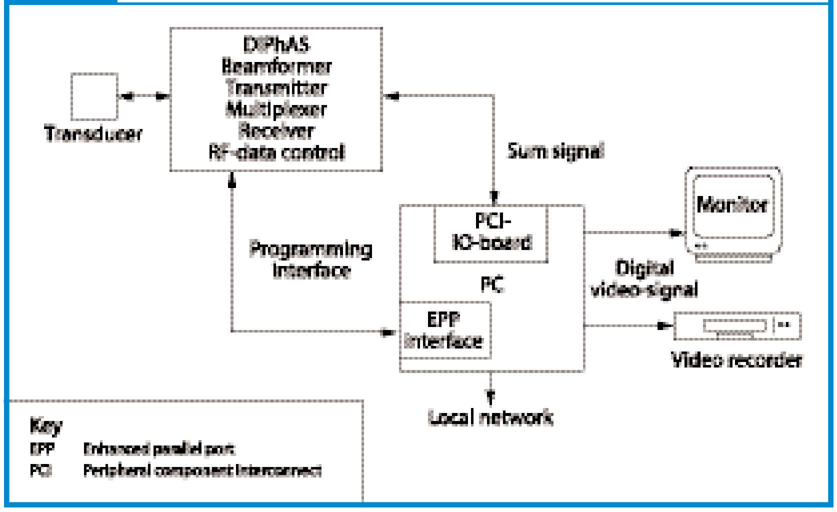
Ultrasound technology was originally developed for cardiac monitoring and prenatal diagnosis, and two major imaging modalities have been improved over the last decades. The Brightness-Mode-greyscale-images are generated by amplitude detection of the reflected ultrasound signal (echoes), and blood-flow information is detected using the frequency shift in the received signal due to the Doppler effect. These techniques have been enhanced with spatial and time resolution leading to real-time, three-dimensional imaging systems that can generate up to 22 volume data sets/s. However, it is only in recent years that new imaging concepts such as tissue harmonic imaging and the use of ultrasound contrast agents have been introduced to the market. Other imaging techniques such as elastography, vibroacoustography and time reversal imaging are still in their infancy.

The lack of new processing methods for imaging has meant that the capabilities of ultrasound seem mainly restricted to diagnostic imaging. New fields such as therapy planning, control and monitoring and intraoperative navigation on the imaging side, and high-intensity ultrasound therapy or controlled drug delivery on the therapeutic side are only just starting to be developed. The main focus of commercial research and development is still concentrated on the improvement of image resolution and contrast.

The need for research systems

These research groups concentrate their work on techniques based on advanced processing of the raw radio frequency (RF) ultrasound data (RF-data) as it is received by the probe. The information necessary for methods such as tissue characterisation, quantitative blood-flow measurement, cardiac motion, vessel-wall analysis or detection of bone-mineral density is hidden in the frequency spectrum of the received signals. Beyond the detection of a frequency shift caused by the Doppler effect and tissue-nonlinearity, which is used for tissue harmonic imaging, conventional imaging methods discard this →

Figure 1: Block diagram of a phased-array system connected to a computer.



information by simply transferring the amplitude to brightness values.

For the extraction of information from the RF-signal, advanced processing algorithms such as pulse compression, correlation, transformation and filtering techniques are necessary, and clinical and nonclinical researchers need direct access to the raw RF-data. Typical commercially available ultrasonic systems do not provide full access to this data and do not allow free appropriate programming of the electrical signal that is driving the probe such as the pulse-compression technique.

Figure 2: Digital phased-array system connected to a probe and a PC with display.

A technique to reduce elements such as false shadowing is to use special scan strategies with spatial averaging. However, a necessary precondition for using or developing these techniques is the full control of the electrical signal of each channel that is connected to each single element of the subgroup. In commercially available ultrasonic systems, fixed dedicated scan strategies and beam-forming techniques are implemented for the different diagnostic modes. Only a few general parameters such as the focus or overall imaging depths are adjustable by the user because radiologists are not usually interested in altering settings during an examination. This is different for engineers who develop new ultrasonic methods. Their interests can only be satisfied by full control of the insonification beam and full access to the received RF-data for signal processing

A platform for research

There is a major difference between a device that is used in routine examinations and one that is used for the research and development (R&D) of ultrasonic applications. The latter should have the character of a toolbox with an interface. It should provide free access to, and control of, all parameters and settings that determine the geometry and temporal shape of the sound beam and access to the raw RF-signal. Although a few commercial companies open their systems to research groups, the best way to meet the requirements of the research engineer market is a combination of designated research hardware and the service for its adaptation to the engineer's special requirements. Figure 1 shows a block diagram of this digital phased-array system (DiPhAS) connected to a computer.

The system consists mainly of three parts: the probe, the PC with its peripheral and the DiPhAS itself. The DiPhAS contains the electronic boards for beamforming, the transmit and receive module, the module for the handling and control of the RF-data and a multiplexor. Usually, the number of the electronic channels of the system is lower than the number of the elements of the transducer because

Figure 3: Block diagram of a modular phased-array system. Each beamformer board contains eight channels and is connected to the parallel boards by an adder. The boards are connected to the probe (transducer) using a multiplexer (MUX). The parts of the control board are at the bottom of the diagram.

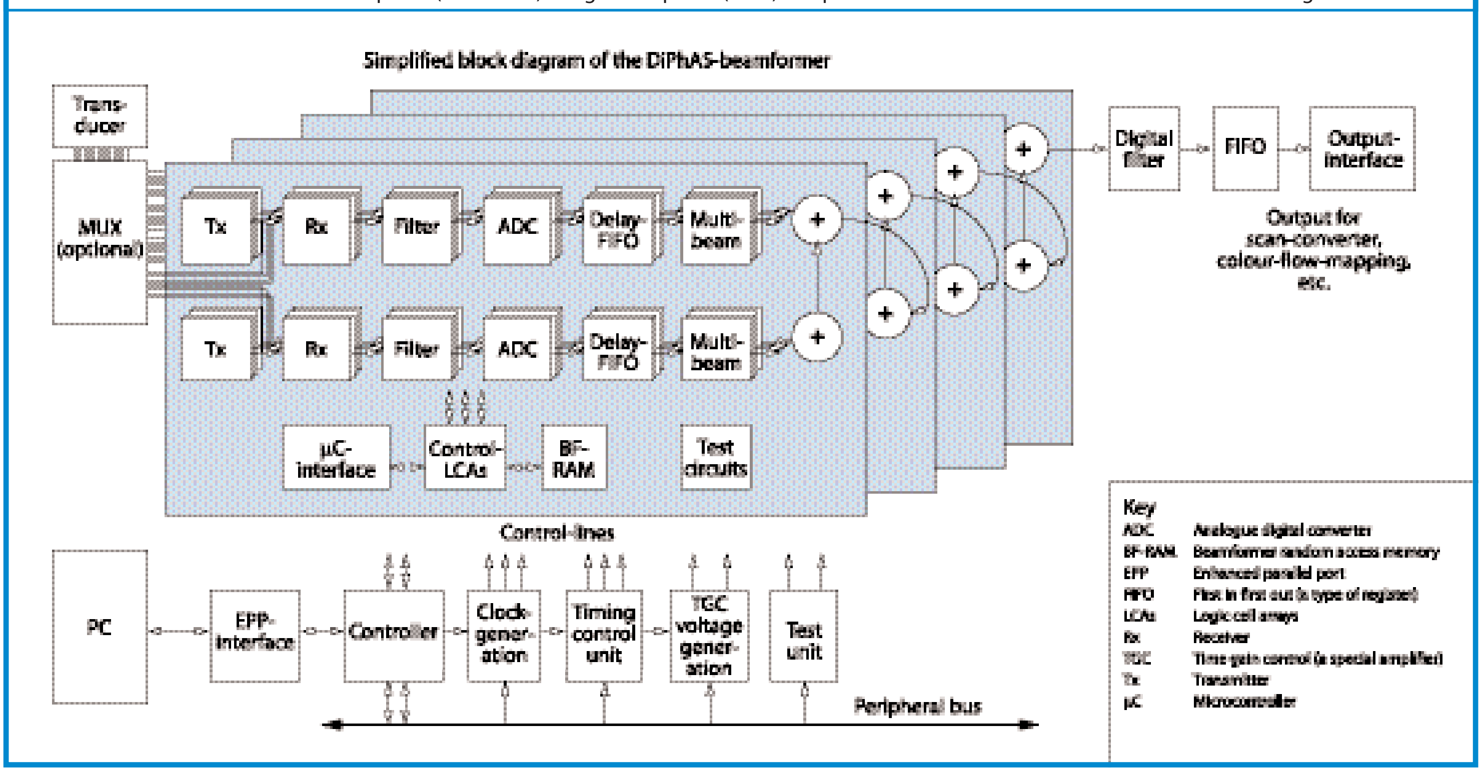
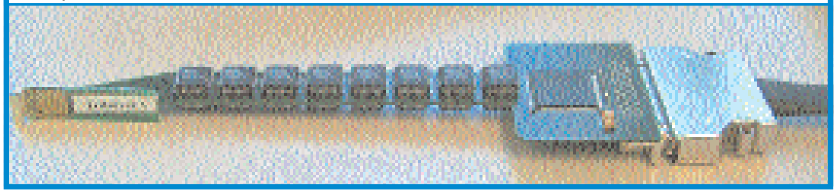


Figure 4: Specialised 20-MHz phased-array ultrasonic prototype probe for gum imaging. The array is at the left tip attached to a small board containing some electronic components for control.



only a subgroup of elements of the probe is used (for example, 64 active elements out of 256). The multiplexor distributes these electronic channels to the appropriate pins of the plug of the probe and controls the shifting of the subgroup across the array. The DiPhAS is connected to the PC via two different interfaces. Through the programming interface the settings of the system such as beamforming and scan strategy can be programmed. The unprocessed raw RF-data are transferred through the high-speed data interface to the computer where they can be processed, displayed and stored for off-line analysis and documentation. This concept of separating the phased-array system from the computer and the probe has several advantages.

Design advantages

Using standard input-output interfaces, the phased-array system is independent of the type of computer. Depending on the requirements for the speed and power of signal processing or data storage, small notebooks up to high-end workstations can be used. Compared with the phased-array system, the innovation cycle for computer hardware is rapid. Therefore, by upgrading the computer, the processing part of the system can be economically maintained at state-of-the-art technology (Figure 2). It is also possible to integrate the phased-array system into an existing hard- and software development environment.

If the phased-array system is designed modularly it can be scaled from a low number of channels up to larger numbers according to the engineer's needs. Figure 3 shows a diagram of this type of system. The system is divided into the beamformer boards and the controller board. Each beamformer board has eight identical channels. Each channel has all parts necessary to drive one element of the array independently from the others. The smallest system consists of one beamformer and the controller board and has eight channels. It can be scaled up in steps of eight channels. Standard systems have 64 or 128 channels.

Arbitrary array probes can be connected to the system using customised adapters. This provides the opportunity to use it as a development platform for many different ultrasonic applications and as a testing and optimisation tool in designing new probes (Figure 4).

Independent of computers and probes, the system can be used as a development platform for new ultrasonic devices. One of the design criteria for the development of the phased-array system is to make it as flexible as possible. The use of high-quality components and the implementation of most of the electronic circuits into Field Programmable Gate Array technology mean that the hardware can easily be reconfigured by programming. For example, instead of using cheap 8- or 10-bit analogue digital converters, a research platform should be equipped with 12-bit converters that give enough dynamic behaviour even for advanced applications. During its use as a development platform for new ultrasonic devices, different hardware configurations can be tested, which allows the possibility of simulating more economical versions. In this way, a new specialised downgraded device with the best trade-off between cost and performance can be designed.

The future

Currently, there are only a few university and institutional groups that have developed ultrasonic phased-array systems working as research interfaces. These systems are operating in the frequency range up to 20 MHz and most of them are used only for the group's own work. A DiPhAS has been developed for the research market that can be controlled using standard software such as LabView (National Instruments www.ni.com) or direct programming in C++ and that can transfer 16-bit raw RF-data at a rate of 40 MHz to a PC for further processing. The system has several implementations in different countries and is used for R&D into new methods in vascular and cardiovascular imaging, therapy control, intraoperative navigation and optoacoustic imaging. Two small start-up companies in Taiwan and the United States are using the system as a development platform for new low-cost diagnostic systems for the Asian market.

A future development direction in ultrasonic methods is the use of higher frequencies up to 100 MHz. Application areas include ophthalmology, cancer detection, tissue characterisation and intravascular imaging. Although single-channel systems are already available for these frequencies, multichannel systems are still a challenge. The hardware concepts currently used cannot easily be transferred to high frequencies, and for the development of array probes new and improved technologies for structuring, packaging and interconnecting must be implemented. mdt

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