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Possible Futures for Medical Ultrasound Technology

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1. Introduction

Medical ultrasound instruments have been available for clinical users for roughly the past 60 years. During this time the field has received deep attention from researchers in academia and industry. There has also been a close coupling between ultrasound scanners and microelectronics which has significantly aided in the development process. In this invited talk this history will be summarized with the goal of defining the starting point of future technical developments of the field. This will be largely discussed from industry point of view.

The history has been divided into four discrete stages: analog (mechanical and array based), digital beamformation based, 3D/4D and handheld scanners, and finally software beamformer based designs. With this background, we will look at the current research interests in the ultrasound community and take another look at the system design of scanners and propose possible changes to the block diagram.

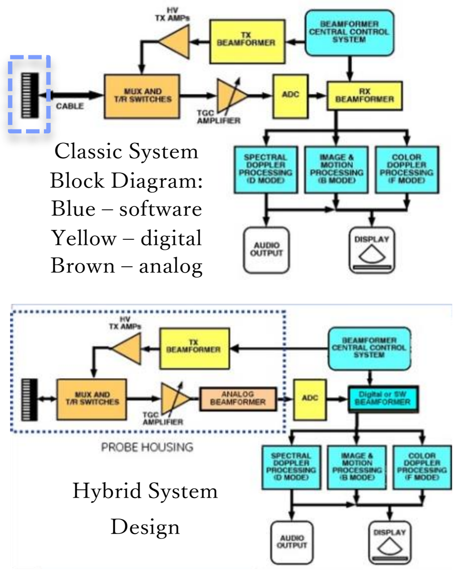

Figure 1. Block diagram changes for 3D/4D imaging and miniaturized scanners

2. Evolutionary stages

The four stages discussed in the Introduction required different design goals and, not surprisingly, different skills with the personnel. Here we will look at each stage in a bit more detail.

2.1 Mechanical and array-based analog scanners

The earliest forms of mechanical scanners were manually moved articulated-arm scanners. For selected modalities such as echocardiology, single element transducers were used to create M-Mode images. With modalities requiring 2D anatomical imaging, mechanically moved single element transducers were developed in the late 1960s and early 1970s. Later in that decade ADR in the USA and Toshiba, Aloka, Hitachi, Shimadzu, and others in Japan introduced real-time linear array scanners[2].

Surprisingly research into phased array scanners occurred quite early with publications back in 1967[1]. However, the introduction of commercial systems had to wait until the late 1970s with the introduction of the Hitachi system. Hewlett-Packard introduced their very popular scanner in 1983. Later clinical use has separated the linear array and phased array systems into radiology-focused and echocardiology focused applications [1,2,3]

2.2 Digital Beamformation

The challenges and limitations of analog beamformers made it necessary to replace them with digital versions. This had to wait until the development of fast high-bit count A/D converters which occurred in the 1990-time frame. While the cost of the new components was higher than those needed for analog beamformation, the relative ease of use and broader applicability caused a rapid change to digital.

2.3 3/4D and Miniaturized Scanners

It was recognized early that echocardiology would benefit greatly from 3D and 4D imaging. Implementation of that capability requires sharply increased element counts in the transducer array, i.e., a 2D array. A patent by John Larson et. al.[4] suggested the migration of a part of the beamformer into the

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ultrasound probe would permit this. This was realized in the work by Bernard Savord et al.[5] These changes are illustrated in **Fig. 1,** which shows an analog beamformer within the probe housing and a standard digital or software beamformer in the main console.

2.4 Software Beamformation

An early pioneer in software beamformation was Verasonics with their development of a research scanner[6]. This development allows academic researchers to implement novel imaging algorithms and observe the results in real-time. This development has depended on increased processing speed realized from multi-core computing engines, heavy use of graphics processor units (GPUs) and high-speed data buses. To-date at least two companies have introduced scanners with software beamformation with more likely to come.

3. Research interests in medical ultrasound

To get a better understanding of the current topics being studied, the oral session indices of the medical sessions of IUS2022 and IUS2023 were grouped into categories. The result is shown in **Table 1**.

	IUS2022	**IUS2023**
Therapy	**9**	**12**
Beamformation	**9**	**7**
Tissue Char.	**5**	**7**
Transduction	**7**	**5**
Contrast Agents	**3**	**4**
Elastography	**6**	**4**
Super Resolution	**5**	**4**
Machine Learning	**2**	**3**
Photoacoustics	**4**	**3**
Blood Flow	**2**	**2**

Table 1. IUS Sessions by Subject Matter

4. Implication of this analysis

The relation of this list to a scanner block diagram has transduction and front-end electronics (not on the list) as the critical first line in establishing data integrity. This is followed by Beamformation and, subsequently, most of the remaining "post-processing" items (Blood Flow, Elastography) and areas such as Tissue Characterization and Super Resolution. Photoacoustics, Contrast, Machine Learning are in a group of their own, however, are unlikely to have a major impact on the block diagram.

Topics of great interest at IUS2023 were estimation of speed of sound and aberration correction as demonstrated by 4 separate sessions on those topics. In **Table 1** I have grouped them with Beamformation. It is apparent that in a software beamformer, the beamformer block may be formed from several separate parts: 1) data acquisition, 2) speed of sound estimation, and 3) image formation with the corrected speed of sound map.

As noted previously, speed of sound estimation and aberration correction are receiving much research attention today. Plane wave imaging is turning out to be a useful data acquisition format for this. With respect to aberration correction, a poster discussed the introduction of a form of it into a commercial scanner[7,8]. Another poster which clearly indicated the potential of software beamformation showed the use of a high-speed computing system with an open-source software package called *vbeam* [9]. Due to the ultra-high speed of the computing system (1e10 pixels/sec), parameters of the simulation could be changed continuously thereby permitting differential beamformation. Thus, new images could be determined in a matter of milliseconds. An image quality metric could be used to optimize the image rapidly, or a training set could be generated for machine learning. The possibilities of what can be researched have grown significantly.

Conclusions

After some 60 years, the evolution of the modern ultrasound scanner has reached the point where most of the processing will be software based. With new research tools, the potential for advances in medical ultrasound have fewer and fewer limitations. Recent conferences demonstrate a strong interest in methods that will take advantage of the most recent computing technology as well as new machine learning methods.

References

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