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Advances in Ultrasound Imaging Architecture: The Future Is Now

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Abstract

Ultrasound imaging architecture, the underlying engineering design and structure that enables an imaging platform to perform its wide and varied array of clinical applications, has evolved significantly over the past two decades. By integrating technological advances and innovative design elements into contemporary premium-level imaging systems, many of the constraints associated with conventional imaging architecture have been mitigated. This progress has opened the door to the introduction of novel diagnostic capabilities into the sonographic armamentarium. Of necessity, then, is the need for a concomitant evolution of educational endeavors; didactic and clinical approaches that will ensure that sonography practitioners remain competent as the future of our profession and scopes of practice unfold. This paper, and the associated supplemental white paper, offers a synopsis of advanced ultrasound imaging architecture that, hopefully, can serve as a springboard for development of similarly evolved educational endeavors.

Keywords

Ultrasound physics, Ultrasound virtual beamforming, Ultrasound digital signal processing, Sonobiometrics

Technological and engineering methods used in ultrasound-based diagnostics have evolved significantly over the past two decades. The architecture underpinning these platforms has advanced to the point where new and advanced diagnostic capabilities are being introduced, somewhat regularly, into the sonographic armamentarium. These novel applications, some of which are not *imaging* methods at all, are made possible by scientific and engineering advances that parallel progress made in other technology-based fields. As the future of our profession continues to unfold, it is imperative that users of these cutting-edge, emerging modalities understand the physical and technological foundations of their tools so that appropriate and accurate clinical interpretations can be rendered.

The process by which ultrasound images are created, as taught in sonography educational programs, has remained virtually unchanged for more than 30 years. While incremental changes have been incorporated into sonography physics and instrumentation (SPI) curricula and certification examination content outlines as generational leaps in equipment have been rolled out, the time is at hand to begin the process of revising both curricula and content to assure continued competency of sonography practitioners; changes and revisions that reflect the sea change that ultrasound technology has undergone over the past 20 years. This editorial offers one individual's experience and perspective on a proposed high-level overview of the foundational pillars of advanced ultrasound imaging architecture that should be integrated into future sonography educational endeavors.

The content of this symposia article is expounded in greater depth in a separate white paper by the same author, which is provided online as supplemental material.

Advanced Ultrasound Imaging Architecture

Conventional ultrasound imaging architecture is constrained by inherent data loss and restrictions on temporal resolution which limits not only image quality and uniformity but also precludes the development of novel real-time diagnostic capabilities. Advances in contemporary platform architecture overcome these constraints by integrating state-of-the-art hardware and software components into the ultrasound imaging chain. While vendor-specific approaches to both underlying technological processes and the marketing and educational

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narratives employed to roll out these advances varies, there are four generalized, generic similarities. (It should be noted that these advanced methods typically apply only to premium-level ultrasound platforms currently competing in the marketplace.) These four technological "pillars" are as follows:

Virtual Beamforming

Conventional ultrasound imaging systems rely on careful control of the geometric and acoustic characteristics of the transmit beam to yield high-quality images. This is accomplished by using timing delays in varying and creative ways to the multiple piezoelectric elements arrayed in the transducer housing. Timing delays can also be applied to the received acoustic data set to further improve image quality. Virtual beamforming, on the contrary, applies software algorithms to the entire received acoustic data set to virtually focus each imaging frame, pixel by pixel, on both transmit and receive. As a result, larger transmit acoustic fields can be generated, in some cases full plane waves, which eliminates conventional channel-dependence and dramatically improves temporal acquisition of data, spatial resolution, and overall image uniformity.[1] As Dr. Fred Kremkau has posited in a recent *Journal of Diagnostic Medical Ultrasound* article, the virtual beamforming approach to ultrasound diagnostics has created a "new paradigm" for understanding, teaching, and testing sonographic principles.[2]

Integration of "Big Data" Methods

Transmitting more robust acoustic insonation regions using broader bandwidth beams generates an enormous amount and variety of information contained within the received acoustic data set. Conventional ultrasound platforms lack the capacity to accommodate this enormous amount of raw data and much of it is truncated and "dumped" by traditional receiver and scan converter operations. As a result, only a fraction of the original acoustic data set remains available for subsequent clinical applications.[3] By integrating hardware and software capabilities characteristic of "big data" methods, these constraints can be mitigated. Big data methods are currently employed in virtually every discipline where enormous amounts of digital information must be analyzed to yield a desired outcome. The ability to acquire, transfer, process, and store these massive volumes of digital data, which in ultrasound applications, represents the interaction of acoustic energy with human soft tissue and provides the potential for a new generation of diagnostic possibilities. Some of these novel applications, particularly non-imaging ultrasound methods, have already entered clinical practice. Quantification of and clinically verified integration of big acoustic data sets present the very real possibility of the new discipline of *sonobiometrics*, wherein histological characteristics of insonated tissue types can be discerned noninvasively—a *virtual histology* if you will—long the holy grail of ultrasound diagnostics.

Enhanced Digital Signal Processing

The enormous size and diversity of the acoustic data sets generated by virtual beamforming methods and captured by the power of "big data" would amount to nothing without technological capabilities to process these data and convert them into practical use. Enhanced digital signal processing makes this possible. While digital signal processing methods have been around for decades, the integration of high-speed, high-capacity hardware components coupled with the development of cutting-edge industry-specific software and graphics capabilities elevates it to a new level. With the digital data stored in channel domain memory, multiple contemporaneous real-time and/or retrospective processing passes can be applied to each received data set at extremely fast rates. This provides an immediate and dramatic improvement in conventional gray-scale, color Doppler and contrast-enhanced ultrasound contrast resolution. And thanks to the inherent properties of high-speed, high-capacity processing capabilities, temporal resolution is maintained regardless of imaging depth or number of modalities employed simultaneously. In other words, front-end, displayed frame rates do not take a hit resulting in a "real" real-time evaluation of the area under interrogation. Enhanced digital signal processing is also an integral component in analyzing, segmenting, and applying artificial intelligence methods to data sets that create "smart" ultrasound platforms that can, and already have, generated yet more advanced automated applications.

Replacement of Line-by-Line With Bit-by-Bit Frame Creation

Conventional sonographic imaging platforms employ a line-by-line frame creation schema. Data loss and limits on temporal resolution associated with this method placed constraints on image quality and diagnostic potential. Bit-by-bit frame creation, on the contrary, uses the enhanced digitally processed output "big data" to populate individual pixels in back-end virtual digital scaffolds. Each of these individual frame scaffolds can be filled with any number of acoustic data types representing the specific applications(s) selected by the operator, that is, gray-scale image, color Doppler, elastography, contrast-enhanced ultrasound, and so on. After each back-end frame is assembled, additional digital signal processing software algorithms can be applied before the frame is presented for operator interpretation. Bit-by-bit creation of thousands of individual back-end frames makes true real-time imaging and data quantification a reality. Evaluation and comparison of individual data points on each of several, or many, scaffolds permit other advanced technological capabilities such as speckle tracking, vector flow hemodynamic imaging, and other temporal domain-based modalities. It is important to keep in mind the distinction between back-end frame rates, which are transparent to the operator and can exceed 1000 frames per second and front-end frame rates, which continue to be displayed at more the familiar 16 to 60 frames per second.

Conclusion

Advances in the technological and engineering underpinnings of medical ultrasound investigation provide the potential for real progress in clinical diagnostic capabilities. No longer confined to familiar and conventional clinical imaging applications (qualitative *sonography*), novel modalities have and continue to emerge which are slowly but surely finding their way into daily practice (quantitative *sonobiometrics*). As with all medical imaging modalities, an understanding of the physical principles and technological pillars associated with the diagnostic end product is essential for users so that they may render an appropriate and accurate interpretation. This article offers, in the author's opinion, a brief overview of the major and most significant advances in contemporary diagnostic ultrasound architectural design. One hopes that it also offers a springboard for further fleshing out and development of educational content and materials that may bring sonography education and the assessment of professional competency into the real world. The future is now!

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Supplemental Material

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