The Evolution of Medical Ultrasound Imaging Systems

John M. Reid

Drexel University, School of Biomedical Engineering, Science and Health Systems, Philadelphia PA 19104

Abstract Since r.f. data are available from ultrasound systems they provide both amplitude and phase information, and are a convenient venue for the Image Processing community. It is a good idea to know what processing has already been done to these data, and what the real limits and some of the needs are.

SYSTEMS

A limit to effective soft tissue imaging is set by the acoustic properties of tissue. The attenuation is roughly proportioned to, and hence the depth and the size of a resolution element are inversely proportional to, frequency. Thus the number of achievable resolution elements per image is fixed. Accordingly, acoustic frequencies from about 1 to 50 MHz are required, depending on the depth to be imaged, or how far the transducer can be inserted into the body. The speed of sound sets the time required for each range line in the image-and hence influences the frame rate.

Effective ultrasonic imaging has required the development and application of innovative hardware; particularly the transducers. These have progressed from single element types to 512 element multi-element arrays in production, with two-dimensional arrays having 128X128 elements in development. The electronics now require many more channels than previously, with dynamic range exceeding 100 dB and, with the introduction of digital methods, even multiple A/D converters.

![Illustrative receiving system](image)

**Figure 1** Illustrative receiving system, with a multiplexer to connect the active elements to the input channels. Note that, for dynamic focus or scanning, that the A/D converters are in the beamformer where they allow delays to be done digitally. Since only eight bit flash A/D converters are available some compromises have to be made for high dynamic range. The outputs of many are averaged together to form image words with more bits. Each A/D must be preceded by a high gain amplifier with time varied gain to compensate for the attenuation that increases with depth, plus an anti-aliasing filter. One such channel is needed for each active element in the array, shown at the left.

Focusing is also done on transmit by delaying the triggers to the pulse generators. In abdominal imaging, where motion is not a problem, the focus can be applied to a section of the image, then a second image taken with the focus set deeper, and so on. The final image is assembled from the sectional images. Weak focusing is used to maintain depth of field.

Ultrasonic beams are narrowed by two methods. Since the lateral beamwidth is proportional to range, switching in more array elements produces an expanding aperture, keeping the resolution constant. In addition true time-delay focusing is used in high-end system to track the position of the reflecting structures, which allows strong focusing without any problem with depth of field.

Display devices have gone from W.W.II CRT's with 200 spots per radius to digital image stores that pre-process the...
data for display on CRT's with thousands of spots available. These digital image stores can now do image processing with software. The earlier systems survive in some applications that require them. The single element types are still used in high frequency catheters, eye and skin scanners for example. Composite piezoelectric materials allow wideband transducers that have opened up new methods, enhanced Doppler, second harmonic contrast and tissue imaging that use a wider range of frequencies than previously possible.

Those doing image processing must contend with some problems introduced by these systems. Some systems may show a bit of aliasing of the higher acoustic frequencies, since this has no perceptible effect on the image. The systems contain, not only the anti-aliasing filters before each A/D converter, but also low-pass filters after them to remove the differing DC offsets of the A/D converters and other switching transients. The system has software or circuits to take the absolute value of the r.f. waveforms to derive the video signal, and then to apply some proprietary signal-to-brightness transfer function. The function assumed by most processors is the logarithm of one plus the video amplitude.

FUTURE OPPORTUNITIES

Three problems remain: The size of the resolution element in sample space, the lack of landmarks in the images and the presence of speckle. The r.f. is sampled at or above the Nyquist limit, which gives many more samples in the range direction that in the lateral direction. Systems usually have as many acoustic beams as elements in the array, although the image stores may interpolate in between them. This change in scales may complicate 2D image processing unless you are aware of it.

The lack of landmarks results from the limited image size, and prevents ultrasonic images from being compared directly with CT and MRI images. The result is that most multimode imaging research does not include ultrasound. This might be possible in cardiac imaging, but only ultrasound can present high frame rate images of the beating heart. A possible solution is the SieScape™ system developed at Siemens Ultrasound. In this system the transducer is slid sideways, approximately in the image plane, and the new image lines are added to the original. The result is a much larger image.

Speckle remains as an important unsolved problem. Recall that speckle results from the addition of echoes from many scatterers within the sample volume. On average such incoherent signals are treated by adding together the signal power, which should result in a constant value in the image. However, the variance of the completely incoherent result is proportional to the mean. The signal is modulated by this, resulting in peaks and valleys roughly equal in size to the resolution element. This obscures the real structures, hides small lesions, and makes many types of image analysis meaningless since the video signal statistics are Rayleigh or "K" distributed over most of the image.

The efforts to do tissue characterization for detection or diagnosis are complicated by speckle, but still are under development. One reason for the fact that such methods are not used clinically is not that they are so bad-but just that the clinicians are so good! (Some of the reasons are discussed below) As you will hear, some methods have successfully derived information on the number of scatterers and the existence of regular structure on scales shorter than the size of the resolution element.

However, although speckle is a problem to many, it is not a very large problem on clinical use! The operator of the ultrasound scanner sees a dynamic image which is constantly changing with tissue motion (particularly in the case of the heart) and is smoother by the averaging in the retina-brain image analysis system we all possess. In some cases an obstetrician can manipulate a near-term fetus and, while it is moving, no speckle is seen! The image only breaks up into speckle when a static image is saved to memory. The same thing happens in cineangiography when the film is stopped-and the quantum noise is suddenly visible.

The technician has much more information available than is in the static image. It can be claimed that the tech makes the diagnosis and selects a set of images that support the diagnosis to the MD, who is missing the complete exam, where the image is dynamic, supplemented with the Doppler sounds being heard, the knowledge of the structures in the adjacent scan planes, and the direct observation of the patient.

So we have a challenge; to produce images with all of the information used by the technicians-since only then will advanced image processing contribute to ultrasound sufficiently to be included into clinical practice.