Chapter 11 : Emerging Technologies and Trends in Industry

I. Image Quality Improvement

- The ultimate goal of medical imaging is to present clinically relevant information thoroughly and truthfully such that correct diagnoses can be made. Hence, improving the image quality has always been an important task. There have been many new techniques proposed and some implemented in order to improve image quality. Generally speaking, they can be broken down to the following categories: spatial resolution, contrast resolution, temporal resolution, image uniformity and sensitivity. A few examples are given in this section.

- Chirp excitation: The acoustic power output of diagnostic ultrasound imaging systems is limited by safety requirements. Unfortunately, there are situations in which the peak power level is met although the average power level is still significantly below the maximum allowed level. In addition, there may be situations where both the peak power and the average power are below the maximum allowed level due to system limitations (e.g., maximum transmit voltage). One way to increase average power output without exceeding peak power output and electrical limits is to increase the pulse duration (i.e., number of cycles). However, this also results in degradation in range resolution.

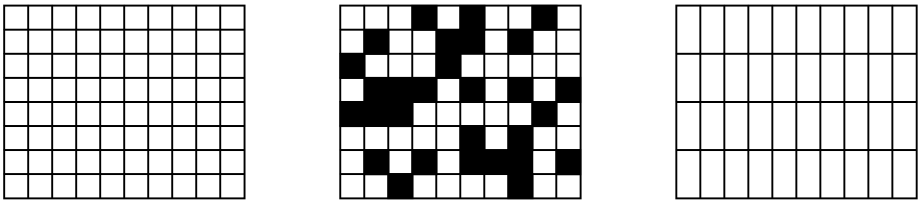
- To achieve both high average power output and high range resolution, chirp excitation has been proposed for ultrasound imaging. A chirp signal can be described by the following equation:

$$c(t) = c_0 \cos(2\pi (f_0 - \frac{\Delta f}{2}) t + \frac{\alpha}{2} t^2),$$

where c_0 is a constant, f_0 is the center frequency, Δf is the bandwidth and α is chosen such that α times the pulse duration is equal to Δf. Since a wide bandwidth is maintained in spite of the increased pulse duration, the range resolution can be achieved by pulse compression (e.g., using an inverse filter or a matched filter). The length of the pulse compression filter needs to be sufficiently large in order to reduce range sidelobes. With the increase in average power output, better sensitivity can be achieved or alternatively, higher frequencies can be used to improve resolution with adequate penetration.

- <u>Large two-dimensional arrays:</u> Current diagnostic ultrasonic imaging systems using one-dimensional arrays have not been successful in cancer diagnosis due to the inability to detect low contrast lesions deep in the body, such as tumors. To improve low contrast detectability as well as present fine spatial detail (i.e., improve both spatial and contrast resolution), the size of the three-dimensional resolution cell (i.e., sample volume) must be reduced. Therefore, large, two-dimensional arrays have the potential to greatly improve both spatial and contrast resolution of diagnostic ultrasound and to enhance ultrasound's capability for cancer diagnosis.

- Several types of two-dimensional arrays have been proposed, as illustrated in the following figure.



fully sampled array sparse array 1.5D array

Fully sampled two-dimensional arrays are essential for real-time, three-dimensional, electronic focusing and steering. Therefore, they are required for three-dimensional volumetric imaging. However, a fully sampled (i.e., interelement spacing in both dimensions is half a wavelength) arrays is likely to have more than ten thousands channels. This is not very practical with current electronic technologies. To reduce the total channel number, sparse arrays have been proposed. This type of arrays avoids grating lobes at the price of increase in sidelobe levels. An alternative approach is to use anisotropic arrays. This type of arrays is under-sampled in the non-scan direction in order to reduce the total channel count. However, they are not suitable for real-time three-dimensional imaging due to the limited steering capability in elevation. Nevertheless, they still provide full three-dimensional focusing on the two-dimensional image plane. This type of arrays is also known as 1.5D arrays. The last two approaches (sparse arrays and 1.5D arrays) are more feasible based on current electronic technologies.

- Increasing the depth of field: Ultrasonic pulse-echo imaging systems typically have fixed focus on transmit and dynamic focus on receive. On receive, the delays can be adjusted as a function of range such that coherent sum can be performed accurately. On transmit, however, delays are fixed for focusing at a particular point and hence image quality is degraded if far away from the focal point. There have been several techniques proposed to increase the depth of field on transmit. One of them uses non-diffracting beams to create a transmit radiation pattern which does not change significantly as a function of range. In addition to implementation difficulties, this approach also suffers from high sidelobes. Another approach is to apply a filter retrospectively (i.e., after beam formation) in order to correct for the focusing error of the transmit beam pattern. The filter effectively performs deconvolution and needs to be both range and angle dependent for optimal results.

- Improved system design: Manufacturers of ultrasonic imaging systems continue to enhance system capabilities such that hardware/software limitations can be minimized and processing power can be increased. One example is Color Doppler. By increasing system's dynamic range and processing power, lower level flows can be detected and differentiated from surrounding tissue. The improvement in weak flow detection significantly increases ultrasound's clinical capabilities.

II. New imaging modes

- Elasticity imaging: Elasticity is one of the main mechanical properties of tissue and may offer great clinical values. Since the human sense of touch can only be used for lesions with relatively significant differences in elasticity and close to the surface, elasticity imaging may be of great value in detecting deep lying lesions in a quantitative way. One of the approaches for (static) elasticity imaging involves displacement imaging and Young's modulus reconstruction. There are also other approaches but all of them are still not yet commercialized.

- Second harmonic imaging: The first application of second harmonic imaging in medical ultrasound was to, in combination with contrast agents, enhance the weak echoes received from flow in small blood vessels. Contrast agents made of micro bubbles are not only capable of enhancing the backscattered echoes by around 10 to 25dB, they also exhibit strong non-linear response. Therefore, the signal strength of the second harmonic signal relative to the fundamental signal can be significantly increased and low level blood flows, such as blood perfusion, can be visualized by using second harmonic Doppler imaging in combination with the injection of contrast agents.

- A new and important application of second harmonic imaging is imaging without contrast agents. In other words, it is used to image the second harmonic response of tissue itself. Interestingly enough, since the non-linear response is strongly dependent on the amplitude of the impinging sound waves, image artifacts are significantly reduced in second harmonic imaging since the non-linear response of the signal is much stronger than that of the artifact. Clinical evaluations showed that the improvement in image quality is significant in situations when severe imaging artifacts are present in fundamental imaging.

- Extended field of view: The current scan formats have either limited field of view or degraded resolution at depth. Extended field of view is a new capability allowing users to obtain a wider field of view using existing transducers without the need of external positional sensors. Image reconstruction is also done in real-time as the user slowly moves the transducer along the scanning direction. Therefore, larger field of view can be obtained without sacrificing resolution at depth.

- Real-time three-dimensional imaging: A real-time, three dimensional volumetric imaging system has recently been introduced to the market for cardiac applications. It utilizes two-dimensional arrays and parallel beam formation to maintain sufficient frame rate. Currently, only limited imaging features are available.

- Conventional three-dimensional imaging: Although real-time, three-dimensional volumetric imaging is expensive and still in its early stage, three-dimensional data of ultrasound echo information can still be acquired by sweeping the transducer in several different fashions. The acquired two-dimensional images are combined and three-dimensional data sets are constructed. Depending on the specific approach, three-dimensional data are then projected and displayed on a two-dimensional plane. Popular approaches for projection include section reconstruction, surface rendering and volume rendering. Three-dimensional imaging is a relatively new area and the full clinical potential is still yet to be discovered.

III. Adaptive imaging systems

- The goal of adaptive imaging is to obtain high quality images (e.g., diffraction limited images in B-mode) independent of the physiological characteristics of the patient. One of the challenges achieving this goal is sound velocity inhomogeneities. Aberrations due to sound velocity inhomogeneities are likely to produce beamforming artifacts since the sound velocity is usually assumed constant in tissue to calculate time delays in forming acoustic beams from arrays. Therefore, sound waves experience wavefront distortion, which produces image artifacts. The phase aberration problem is more pronounced if a larger array or a higher frequency is used to increase resolution.

- Extensive research has been conducted on phase aberration estimation and correction. One method based on cross-correlation of received signals between two array elements has been shown to be robust even in the presence of distributed scatterers. This method assumes that the phase aberrations can be modeled as a simple phase screen at the face of the transducer and therefore aberrations can be corrected by adjusting the time delays. In practice, however, aberrations may be distributed in range, thus making the phase screen model invalid. In addition, the relatively large dimension in the non-scan direction of a one-dimensional array also affects the accuracy of the estimation.

- Other examples of adaptive imaging include automatic gain compensation, automatic wall filtering, automatic flow estimation, …etc.

IV. Miscellaneous

- <u>Hand-held device:</u> With the advancement of electronic technologies, not only image quality can be improved and new functions can be implemented, the size and cost of a system can also be dramatically reduced without sacrificing performance. Specifically, conventional circuits in a system can be integrated in a few application-specific integrated circuits (ASIC's). To date, hand-held scanners have been commercialized and may potentially further increase the diagnostic value of ultrasound. Note that hand-held scanners are not direct miniaturization of current systems, the imaging techniques and signal processing algorithms must also be modified accordingly.

- <u>Automatic Doppler:</u> As we discussed previously, Spectral Doppler is suitable for quantitative analysis due to its accuracy in frequency estimation. In a clinical situation, the operator is often required to measure specific points in the Doppler strip (e.g., maximum in systole). To reduce scanning time and to improve the robustness of the measurements, automatic Doppler, which is a real-time automatic trace of some aspects of the Doppler waveform, is being developed for better hemodynamic evaluation of blood flows.

- Image management: Medical ultrasonic images are often archived by using hard copies, films or stored on video tapes. With the advancement of digital technologies, images can be stored in a digital format to reduce cost and space. In addition, images can be transmitted to a remote site via communication networks. Some recent systems store images and patient information directly on a local media, without using an external device.