Performance Parameters I: Defining Performance Criteria

Hector Lopez, Sc.D.

Today's ultrasound imaging systems produce better images and display more information than it was possible to display 30 years ago. Similarly, performance criteria for ultrasound imaging systems and the tools used to make these measurements have evolved, and have become more complex. This presentation will informally discuss a few examples of the evolution of ultrasound imaging systems and performance measurements over the past 30 years.

Background

Measuring the performance of any imaging system is difficult because it involves both quantitative and psychological factors. The quality of images produced depends not only on the physical parameters that theoretically make an image better, but also on the user's ability to see the diagnostic content in the images. The resulting diagnosis depends on the observer's ability to recognize a wide range of structures in the body, imaged at different sizes and levels of contrast. A good diagnosis requires that the observer be able to detect structures that can be identified as different from the background, and further differentiated as benign or malignant. The spatial resolution capabilities of the system and the level of noise present in the images can interfere with detecting the presence of possible lesions, or in being able to differentiate them. The system should have sufficient resolution to be able to display fine structures, such as the shape and boundaries of the lesions and the possible presence of acoustic shadowing or enhancement.

For the bistable images that were produced in the 1970's, image evaluation criteria were simple. Since there was no gray-scale capability, the main concern was in making sure that the images accurately represented relative distances and object positions. For those images, it was sufficient to describe very basic measurements of axial and lateral resolution. Another concern was the concept of "registration", or ability to make co-incident or overlapping images of the same point object scanned from different angles.

As technology improved, gray-scale capability was introduced, and evaluation criteria expanded to include gray-scale transfer function and maximum depth of penetration measurements. Later, new imaging capabilities evolved, such as real-time imaging, electronic focusing, broadband transducers, and a wider variety of transducer types. Recently, more advances have been introduced that further improve the quality of images by reducing the noise level. For instance, harmonic-frequency imaging and multiple-angle compounding are designed to reduce noise and improve image contrast.

Evolution of Performance Criteria and Testing Methods

Similarly, as technology has advanced, evaluation criteria for most current ultrasound imaging systems have gradually expanded to include most of the factors and criteria that are used for other, more mature imaging modalities. Still, some differences remain, since ultrasound imaging physics is slightly different from that of most other imaging modalities. These differences will be discussed later in the presentation.

Manufacturers of ultrasound phantoms and test objects have had a constant struggle in keeping up with improvements in imaging capabilities and expanded performance criteria. Over the past 30 years, phantoms and test objects have ranged from wires in water (the original AIUM 100mm test object) to nylon strings in tissue-mimicking gel, to other tissue-mimicking materials and structures varying in size and contrast, set against a background material. Some of these phantoms will be discussed, along with the rationale for their use.

Physical Properties and Evaluation of Ultrasound Images

In physical terms, the quality of an image is often described in terms of image resolution, contrast and noise. For ultrasound images, the concept of speckle is important to understand, but difficult to deal with, since it does not occur in other imaging modalities. Speckle arises from the coherent nature of ultrasound waves, and represents both noise and unwanted artifact. In assessing the quality of ultrasound images, the speckle in the image must be measured and characterized. This presentation will provide a short discussion of ultrasound image noise statistics and the relationship between speckle and system resolution in terms of the signal-to-noise ratio. Further, a discussion will be given concerning the relationship between contrast, threshold resolution, and speckle statistics.

Although phantoms and test objects are very useful tools, there are problems associated with their use. The evaluation of image quality is often achieved by making visual assessment of images of test objects or phantoms by human observers. One large problem is the amount of error that is introduced in making these observations. This presentation will discuss some subjective test methods that have been used, and the relative levels of error associated with these methods.

A discussion will be given concerning the use of a machine-based observer, which we call the computational observer, that attempts to increase the accuracy and reproducibility of performance measurements, while reducing observer error. A comparison will be presented of the performance of the computational observer compared to that of the human observer.

Looking Ahead

Finally, there will be a discussion concerning the significance of performance measurements using phantoms in light of the amount and sources of error, and how these are measured. Another discussion will be given concerning the transportability and significance of data measurements performed with one phantom at one location, compared how this relates to measurements performed at other laboratories, using different phantoms and imaging systems.