The New Dimensions in Quality Measurements of the Ultrasound Diagnostic Instruments

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Introduction

Essential improvements and new methods of the ultrasound instrumentation quality assurance measurements have been developed, exceeding the all relevant IEC and AIUM recommendations.

With the introduction of methods for objective system performance measurements using digitized video output (AIUM Technical Standards Committee: Methods for Measuring Performance of Pulse-Echo Ultrasound Imaging Equipment, Part II: Digital Methods, 1995) computer evaluation of phantom images really took it's beginning. At the same time this however triggered an abundance of the subjective quality assessments. The AIUM and IEC decision to do it "objectively", did not in the first place solved the problem of calculating the system parameters from phantom images. To achieve this it was necessary:

1. to develop new phantoms suitable for objective quality determination
2. to find the proper way for system parameter calculation from phantom images using adequate computer processing

In the beginning both items where in an embryonic stage. Although phantoms, making use of spherical voids as suitable targets had been proposed long before the awareness of the necessity for digital methods, confusion prevailed over phantom image processing. The attempt to process the images from this generation of phantoms failed. The awareness for the necessity to develop both, new phantoms and new image processing, grows slowly.

IEC - International Electrotechnical Commission

AIUM - American Institution of Ultrasound in Medicine

The proposed spherical voids, accepted by the IEC as phantom targets, show high alignment sensitivity in all directions when using automated measurements. It is not easy to precisely "hit" several targets in the B-plane, especially if the targets are very small (1mm). In the IEC recommendations (document TC 87/165CD Ultrasonics Measurement, 1999-8-5) it is specially noted: "...to take the care to align the scanning plane with the plane containing the centers of the spherical targets". Using visual evaluation of the phantom real-time image there is some chance to "see" the targets in the resolving range, but for processing of the phantom images from a single picture there is little chance to properly adjust the B-plane without alignment mistakes.

Solution of the alignment problem

The only way to solve the alignment problem in all directions is taking a 3D-volume image as an image sequence with a 3D-Region of Interest (3D-ROI), which is sure to include all targets of interest . Inside of the 3D-ROI the program must provide "auto-detection" of the targets using tracking algorithms and then calculate the spatial position, volume and signal to noise ratio (SNR) for all targets "found". This process may be fully automated without any alignment error and is highly reproducible.

There is the question which shape of target is most suitable to meet all requirements of quantitative quality control. The best solution found is the cylindrical shape - the common shape of the blood vessel. Small cylindrical targets, with their axis parallel to sound propagation direction, reduce the sensitivity to alignment in the C-plane without any drawback in azimuth and elevation directions. That target is familiar to all sonographers and they are used to recognize the blood vessels in all positions, orientations and sizes.

Furthermore, the cylinder shape with its axis oriented parallel to the US-propagation direction may be discriminated more easily from other "virtual" shapes generated randomly by the speckle. This fact allows the use of the very small cylindrical targets down to 1.5mm and 1mm diameter.

The big advantage of 3D image processing is the chance to apply special 3D-morphological filters. Why we need 3D-morphological filters is evident from following example: The cross section of a cone may be a "circle" or a "triangle" and it is evident, that from cross section alone it is impossible to determine which type of 3D-shape it will turn out to be! The assessment of any such shape from its cross-section-image is very ambiguous! The proof for this statement may be confirmed both using mathematical models and experiments. The matching of a morphological filter to a cylindrical shape will allow a more precise separation of the targets from surrounding image speckle with high SNR. When matching with spherical targets, an equal SNR can not be achieved and a wider ambiguity range results.

The use of 3D-morphological filters adds a new dimension to quantitative sonography. Qualitatively it is the daily job of sonographers to reconstruct the different anatomical shapes from series of image slices in vivo. It all happens in their minds (memory) and is a most sophisticated function of the brain. Unfortunately the brain cannot performed this process quantitatively. In shape reconstruction from any 2D information source (normal 2D image) the brain outperforms any computer processing, especially in ultrasound imaging where we have inherently poor SNR. In this special case, using 3D-morphological filters, there however exists a certain advantage of the computer over the brains processing, not only for quantitative evaluations: In the huge amount of data acquired for a volume image nothing will be "overlooked" by computer, although only limited algorithm abilities can by applied in the processing domain. Measurement of the brains spatial reconstruction ability is a very difficult task. The decision in an ambiguous and noisy situation strongly depends on the experience of an observer and will even change during a day depending on observer fatigue. A large number of unprejudiced and experienced observers would be necessary to meet a fairly unbiased decision about information content of an ultrasound image.

3D Data Acquisition

Most of the ultrasound instruments in use are supplied with a video output and this is, according to the AIUM standard, a suitable source for image digitizers. The volumetric image digitizer, which is supplied with the quality assurance equipment described comprises a scanner-head-fastener and a moving-platform for the phantom and is an indispensable accessory for the acquisition of volumetric images. If the moving-platform provides the constant speed (e.g. 1mm/sec), a correct geometry may be achieved by a frame grabber with adjustable image acquisition rate (images/sec). For 3D ultrasound instruments the image data may be taken directly from the corresponding storage devices or scan converters. If only gray scale B-images will be processed, the images taken by the frame grabber may be changed to monochrome. In general loss-less compression of the image data may be recommended in order to reduce the huge files which are common in the volumetric image acquisition. Any data compression resulting in losses are not acceptable for medical use.

The automated processing of the volumetric images requires a careful setting of the 3D-ROI. Special care must be taken to avoid the superfluous processing of irrelevant data sets, because the huge 3D data blocks normally need plenty of the processing time, even when using very fast computers. A clear presentation of the image data, before the start of the processing, is a necessary condition for an efficient solution of the task.

Special care has to be devoted to the adjustment of the scale. The scale adjustment influences the processing in each step and incorrect result have to be expected when using badly set scales. Fully automated transfer of the scale is only possible with transfer of all geometric data directly from the ultrasound instrument.

Data Processing

Basically 3D-morphological matching filters (3D-MMF) prepare the data in 3D-ROI for successful data segmentation, a frequently used process in image data processing. The only difference with respect to the 2D image processing, is the extension of the filters to the 3D data set and the adjustment of the known algorithms to the new 3D situation. The 3D segmentation of the volumetric images follow the "auto-detection" process using a 3D tracking algorithm. This is the typical recursive "tree" algorithm, as described by 2D image processing, with an extension to the third dimension.

The main problem of the processed data is the simple presentation of results. Although many refined and elegant presentations have been developed, none of them show all profiles and dimensions of a 3D data set. The fast dynamic change of cross sections and profiles seems to fulfill the task better then any sophisticated presentation program.

When processing very noisy data, as it is the case by volumetric ultrasound images, it is purposeful to show the presence of this noise. Independent how the threshold in the segmentation process is precisely selected, the "validation of the noise level" in the result shows the contamination level. This type of presentations are not the "smooth curves" but discrete point diagrams complemented by numerical tables.

Processing Results

The processing strategy has been developed according to the 3D mathematical models of ultrasound propagation and image formation. In homogeneous propagation medium the principle of the volumetric convolution holds. That simplifies the modeling if the point spread function (PSF) in the certain range may be kept constant. The models clearly show the dependence between spatial bandwidth and speckle noise of the volumetric image. Unfortunately, the speckle is an **inherent appearance of the band limited systems** and cannot be eliminated, but the precise knowledge of the laws of speckle generation help to find the optimal image processing for extraction of the useful and relevant volumetric image information.

The main goal of the phantom volumetric image processing is to find the a priori known targets and assess the system parameters, such as the contrast and spatial resolution in dependence of the depth. Volumetric processing allows to calculate the volume of the artificial cysts and lesions. The accuracy of calculated volume depends on SNR of the concerned target. In regions with poor contrast small cysts will look just like "negative" lesions. Small contrast targets thus cannot be discriminated from small cysts. When looking at larger artificial lesions there are possibilities to discriminate them from cysts, but only as long as the scanner is not defective. **Defective scanners, however, may produce strong side lobes.** These side lobes fill the artificial cysts with echoes and once again they look like lesions. In order to avoid this cyst-lesion ambiguity, the use of both types of targets in the same phantoms cannot be recommended. The recommendation of AIUM and IEC to including small targets with different contrasts thus not robust enough especially for quality control using automatic volumetric phantom image processing. Once the system parameters are known, the basic knowledge exist for resolving between cyst and lesions, because the influence of side lobes measured on artificial cyst is known.

The poor contrast caused by side lobes can be very strong for the defective scanner. Sometimes the effect of the side lobes is obvious but unfortunately there also exist the creeping defects, which can be only be recognized quantitatively in the contrast reduction on the larger artificial cysts with reflection distance to the surrounding from > 60 dB.

The system parameter as axial, azimuthal and elevational resolution are parameters which need precise definition. Without this definition it is **impossible to express them quantitatively**. The best way found to calculated them is to take the maximal gray level gradient at the edge of the voids in three directions. Although this method delivers credible results, it is not completely obvious how the quality of the image depends on these system parameters. The relevance of separated resolution parameters to the clinical observations has never established and the spatial resolution measured for voids always seems get more appreciation from clinical point of view. A finer analysis of the instrument quality would need a precise measurement of gray level distributions and speckle structure.

Much more important is the measurement of the instrument quality for the application on inhomogeneous medium as breast. The inhomogeneous medium **inherently produce side lobes** which are not to observed at homogeneous tissues or phantoms. For detecting the side lobes generated in inhomogeneous tissue, similar method as for the void analysis may be applied.

Conclusions

The volumetric image processing is a very promising powerful method for automated quality control. It takes only a few minutes for performance evaluation when using tissue mimicking phantoms specially suitable for that kind of automation. The main problem of automated performance evaluation - very sensitive B-plane adjustment to the "target plane" - known as alignment, is totally eliminated. The elimination of the alignment problem allows the application of the target diameters as small as 1mm, especially important for new generation of 1.25D, 1.5D, 1.75D and 2D wide band and high frequency scan head technologies.

The new method is encouraging and should permit to redefine instrument quality parameters. These new definitions should allow to achieve a very high level of agreement between human observers and measurement results.

Special care must be taken to observe the difference in imaging quality for homogeneous and inhomogeneous media. The side lobes, generated in an inhomogeneous medium as breast, reduce the contrast and **cannot be neglected in general performance quality assurance tests**, as they have in the past been neglected by most of the standard recommendations. The human observer needs a high level of awareness about the instrument quality parameters and overall system quality parameters including the specificity of the patient tissue. The volumetric image processing will give the chance to determine and express the overall system quality parameter quantitatively.