Quality Control Automation of Ultrasound Scanners

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Abstract – **Advances of scanner technologies and their versatilities stimulated the development of more precise and faster methods for determination of ultrasound instrumentation quality. Precise measurement of quality parameters is mandatory for a successful determination and assurance of their constancy during the ultrasound instrument life. The measuring automation help to minimize the influence of human factors on measuring results. It is achievable with volume acquisition of ultrasound images, suitable frame grabbers, and 3D artificial cyst phantoms. The new 3D approach would be greatly supported by adequate changes and redefinitions of instrument quality parameters defined in AIUM and IEC standards.**

INTRODUCTION

Automation of quality parameter measurement follows the long period of assessing the quality parameters by observation of ultrasound phantom images. The early begin of measurement is concentrated on estimation of geometric accuracy or registration. The arrangement of nylon threads immersed in water is the first described object for such measurement. Later the measurement is essentially improved by insertion of a nylon thread arrangement in tissue mimicking material with attenuation and backscattering similar to the liver [1].

Unfortunately the practical targets, such as nylon threads, are reflecting objects that are not typical for any object we met in living tissue. They do not deliver promptly enough information about instrument quality.

By observation of real time ultrasound images, certain 3D reconstruction takes place in the human mind. Although such reconstruction is perfect by a trained observer, it is very difficult to imagine, how the image looks from e.g. a blood vessel, if only the image of the basic point reflector is known. This impossibility to use the reconstructed data objectively, “stored” in a human mind, stimulated the idea to use the more complex objects and construct the phantom with anechoic masses or voids similar to the small cysts or blood vessels [1]. The voids a short cylindrical or spherical anechoic objects are suitable targets for estimation of **spatial resolution** and **spatial contrast resolution** objectively**,** without an experienced observer.

The ultrasound images of small cystic objects are strongly dependent from the ultrasound **beam shape**. The beam shape is characterized by two main components: the **main lobe** and the **side lobes**. Side lobes generally, like “spikes”, symmetrical surround the main lobe and are always present. The **relation** between the main lobe and side lobes depend on the scanner geometry, propagation medium, and depth. The anechoic masses appear in the image, caused by the side lobes, are **never echo free**. The side lobes “fill“ simply the voids with echoes. This “filling” may reach the level that the void image cannot be differentiated any more from the surrounding. It happens mostly in the near field. If the power of the side lobes reach the level of the main lob, the edges of the void can be recognized, but the void inside is filled with echoes, almost so high, that it is hard to differentiate it from the void surrounding. It means that in spite of the high spatial resolution the voids almost “disappear” caused by the low spatial **contrast** resolution.

In order to find the side lobes influence character, the anechoic masses have to be completely scatter free. If this condition is not fulfilled, it is a problem to find out, if echoes inside of the void are caused by side lobes or are caused from scatterer inside the voids.

Outside "resolution zone" [5], mostly in the near or the far field, are voids not detectable any more. The "image noise" predominate. If the signal standard deviation and mean of noise inside the void (σ_2, μ_2) is equal the standard deviation and mean of the void surrounding (σ_1, μ_1), then the spatial contrast resolution is zero. Otherwise the contrast resolution for a certain void is [4]:

$$C = (\mu_1 - \mu_2) / \sqrt{(\sigma_1^2 + \sigma_2^2)/2}$$

Void size [mm]

Depth [cm]	1	1.5	2	2.5	3	4
1						*
2					*	-
3				*	-	-
4			*	-	-	-
5		*	-	-	-	-
6			*	-	-	-
7				*	-	-
8					*	-
9						*
10						
11						
12						
13						
14						

Table I. Limits of contrast resolution

For the practical calculation is $\sigma_1=\sigma_2=\sigma$. The following expression for spatial contrast resolution may be used:

$$C = (\mu_1 - \mu_2) / \sigma$$

The contrast C, as the ratio of means and standard deviation, is independent from the gray level dynamic setting.

The limit for the void detectability is taken by the empirical value C=2.5 [4]. The range given with values >2.5 is resolution zone, focal range or "useful range".

The spatial resolution and spatial contrast resolution may be conditionally estimated directly from the phantom image if the phantom is supplied with **void sizes reaching the resolution limit.** The table with the depth scale and the void size scale, is a practical tool for the presentation of the results. The maximum spatial resolution can be found at the top of the "wedge" (see table).

The limit of spatial resolution may be found from the phantom image. However, the spatial **contrast values outside limits cannot be estimated precisely enough by observation.** For such purpose the acquisition of the phantom image and image analysis is necessary. The main problem by the phantom image acquisition is to meet the proper alignment of the scanner B-plane with the voids plane [4]. By voids under 2mm diameter, it is almost impossible to adjust the scanner B-plane coplanar with the voids plane accurately. A small error already influences the result essentially.

The voids intentionally filled with scatterers, of higher or lower density as the surrounding, will be used as **artificial lesions**. Targets structures of this type may be used only in ranges where the influence of side lobes may be neglected and calibrated backscattering ratio of artificial lesions to surrounding is not influenced. In automated quantitative determination of a spatial contrast resolution, such targets cannot be suggested, as they lead to an ambiguous result.

SPATIAL RESOLUTION AND SPATIAL CONTRAST RESOLUTION

The spatial resolution is a "combination" of axial, azimuthal and elevational resolution. All three aspects of the resolution are involved in the target detectability [3]. The target which is appropriate for the determination of the spatial resolution and the spatial contrast resolution must fulfill certain conditions. These conditions will be successively explained and justified.

The elevational and azimuthal resolution will be measured in laboratories on the point reflector in a water tank. As "point reflector" a small stainless ball will be used. Although the ball surface shows the unavoidable coherency effect, it is impossible to reduce the surface of the reflector to an ideal point. The volume contrast resolution ability of a scanner may be determined by **taking in account all side lobes found in the surrounding**. Such measurement is very time consuming and limited only to a scatter free medium.

For the determination of the volume resolution in an attenuating and scattering medium, the **"complement" target**, as a small anechoic "ball" is convenient. The synonyms for anechoic object are "artificial cyst" or simple "void". Such an object is largely coherent free. The spreading of the side lobes echoes takes place outside and inside of the void. Thanks to the echo free voids, "side lobes scattering" is in the **void ultrasound image visible**. If the voids are not scatter free and designed as an artificial lesions, the scattering from a lesion inside will be **superimposed** to the side lobes scattering.

The targets with a strong coherent component may be qualified as "high contrast targets" (nylon thread, steel ball). The objects with spatially random distributed scatterer have low level of coherency and belong to the "low contrast targets". If the contrast is accepted as a relation between the main and side lobes, then **the void is almost an ideal object in the scattering medium** for identification of this relation. If the cross section of the void, in plane perpendicular to the sound propagation is a **circle**, then there is no prevailing direction in the resolution estimation. If this condition is not fulfilled, one of the resolutions may pretended to appear better or worse than it is expected.

The void suitable for measurement volume resolution and volume contrast resolution are small spheres or short cylinders with axes parallel to the sound propagation (**cross section circle!**). All other shapes such as nylon threads or long **conical and cylindrical targets**, independent if they are high or low contrast targets, are **unsuitable** for the measurements of volume resolution and of volume contrast resolution because such targets prefer one of the resolution direction and **pretended to show the non existing quality!**

The typical demonstration of the high spatial resolution and low low contrast resolution on the same voids may be observed in the near field by almost all scanners. In this range is the main lobe mostly very narrow and the **edges of the void appear "sharp"**. The presence of the side lobes in this range "fill" the void inside, causing the reduced contrast.

As an example may by taken the nylon threads imbedded in a scattering tissue mimicking material. The nylon thread appears in B-image e.g. in focus of a linear array as a point. There is no way to tell how large the surface of the nylon thread which contributes to reflection is. It depends on the invisible beam size (wideness) perpendicular to the B-plane. Using a multi-focal setting of the liner array the image of the nylon threads is a **misleading affair**. The threads appear as points in a large range pretending to deliver a high resolution in all depths. In planes, perpendicular to the B-plane (in C- and B'-plane), the cross section looks essentially different. In the B'-plane linear array it appears as a **fix focus scanner** or popular said, shows the corresponding **slice thickness** in all depths.

Similar **pretending exists by low contrast conical or cylindrical targets**. The "filling" of the side lobes at such targets may be **essentially lower** than by targets with a circular cross section. It pretends to show essentially higher volume contrast resolution and better quality parameters than it may be expected.

If a "nylon threads", "conical targets" and a similar targets are not used, there doesn't exist the possibility of a pretending and a results manipulation by inappropriate interpretation.

WHAT CAN'T BE MEASURED BY PHANTOMS?

There are different opinions about the ability of phantoms to represent the living tissue in the estimation of the ultrasound scanner quality. This sensible question must be discussed in detail.

The phantoms are acoustically homogeneous objects and in the sense of homogeneity corresponding to e.g. the normal liver. There is the question what happens with the “image quality” if the liver is behind an inhomogeneous abdominal wall? As the ultrasound penetrates the abdominal wall twice, this doubtlessly changes the beam shape with side lobes, sometimes even essentially. The sound waves penetrate repetitive fat and collagen slices and reverberate between them. Phase aberrations are the results producing additional and unavoidable side lobes. (The technique for eliminating the side lobes in an inhomogeneous medium is object of intensive research).

The homogeneous phantom does not show this effect. With a 2-3 cm slice of animal fat between scanner and the phantom (as stand of), it is possible to observe the results of the phase aberration. An interesting phenomenon can be observed. Using the phantom with nylon threads, the generation of the side lobes do not become evident. However, using a phantom with anechoic voids, the voids “disappear” more or less in noise generated by the side lobes.

Some ultrasound instrument producer use the technique of spatial compounding. They do not explain the consequences of such techniques and the user is not aware of this effect. Such a scanner is excellent in a homogeneous medium but very problematic in an inhomogeneous.

Independent of details, of how the spatial compounding is designed, large scanner aperture causes pronounced phase aberration in inhomogeneous medium. These differences cannot be detected by any homogeneous phantom. Because of the mentioned disadvantages in an inhomogeneous medium, the spatially compounding technique is not very common.

PHANTOM AND AUTOMATION HARDWARE

The phantoms for the determination of the spatial resolution and spatial contrast resolution recently appeared at the market, although the idea to measure the resolution on voids appeared many years ago. The problem with phantom production with small voids is the main reason of this late appearance. For the successful detection of the side lobes by scanners of any type, the **voids must be scatter free**. In order to reach the same attenuation in voids as in the surrounding, it is necessary to fill the voids with an attenuating material – such as a very fine powder. Any agglomeration of this powder produces a “wild” coherency and some echoes appear inside voids. If the voids have not the same attenuation as the surrounding, acoustic “enhancements” or “shadows” will appear. A phantom with enhancements and shadows is not suitable for the quantitative determination of the spatial resolution and the spatial contrast resolution.

The problem of **echoes free voids** can be solved alternatively with a slice phantom structure. The voids are positioned in horizontal slices with very low attenuation. The slices with high attenuation are void less. This way shows the possibility to produce the echo free voids with an echo ratio to the surrounding of more then 60 dB. The condition is to fill the phantom with a degassed water. Sound speed correcting materials have to be a fluid or a fully solvable salt.

The choice of scatterer in the attenuating slices decides about the frequency dependence of the scattering. The blood particles shows clear f^4 frequency dependence. The particles with similar shape shows the same dependence. The particles with shape of a short fibers show typical f^1 dependence. Artificial foams fulfill that dependence and foam is suitable as a tissue mimicking material for a wide frequency range.

The phantom with **sizes of voids reaching the scanner resolution limit**, deliver directly the maximal spatial resolution. Otherwise the estimation of maximal spatial resolution must be performed.

For a 3D image acquisition it is suitable to use a slowly linear moving platform. If the phantom on the platform move 1mm/sec, suffice for many applications 10 image/second. For measuring purposes it is advisable to use the volume phantom image with cube voxals (volume pixels) for practical reasons.

VOLUME IMAGE PROCESSING SOFTWARE

The image acquisition is an interactive action of selecting the volume parts, which are found necessary for the processing of the volume image. The selection of voids in a diameter range from **1mm to 4mm,** depends on the scanner nominal frequency, maximal spatial resolution and scanner main use or application.

The interactive selection of the input data has 3 steps.

1) Selection of the processing frame
2) Selection of the first image
3) Selection of the last image

These steps define the 3D **R**egion **O**f **I**nterest or volume ROI.

Next step is the adjustment of the scale with the selection of pixel/cm. The improper settings will be indicated.

PROCESSING RESULTS

The result shows "useful range" of the scanner with the maximum contrast resolution in the corresponding depths for selected void size, quantitatively. The limit of void detection is assumed as S/N=2.5 [4]. The void detection-limiting factor is the spatial contrast resolution. The axial, azimuthal and elevational resolution expressed (redefined) as spatial resolution is not dominant in detection criteria. In cases with high level of side lobes, the resolved targets may be just recognized over the noise level caused by side lobes.

USING QUALITY ASSURANCE WORKSHEET

The quality assurance worksheet is a document of quality parameter measurement. The automation simplifies the procedure and protect it from subjective assessments.

Using the acquisition via video outputs it is necessary to check the video outputs of ultrasound instrument at least by hard copy printer. The detailed test of the video interface cannot be performed by a phantom.

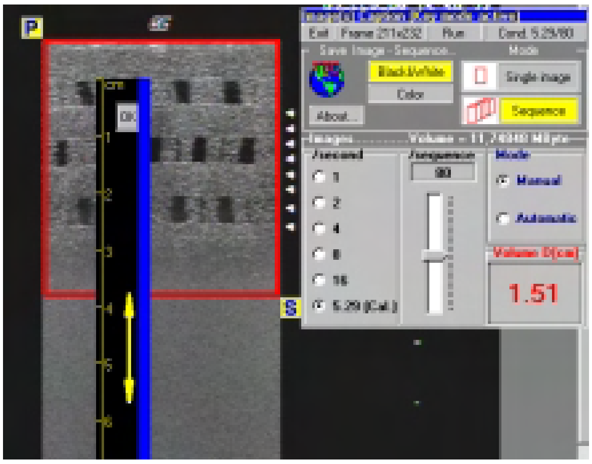

Fig 1. Acquisition of images using universal interface.

A special dynamic test of antrasound instrument including video interface may be suggested [2].

If the ultrasound instrument is equipped with S-VHS video output, this has to be preferred to the VHS output. Most of the frame grabbers are equipped by S-VHS input.

The universal interface as well as any other system may be used for the image acquisition. Fig.1. shows the image acquisition using an universal interface.

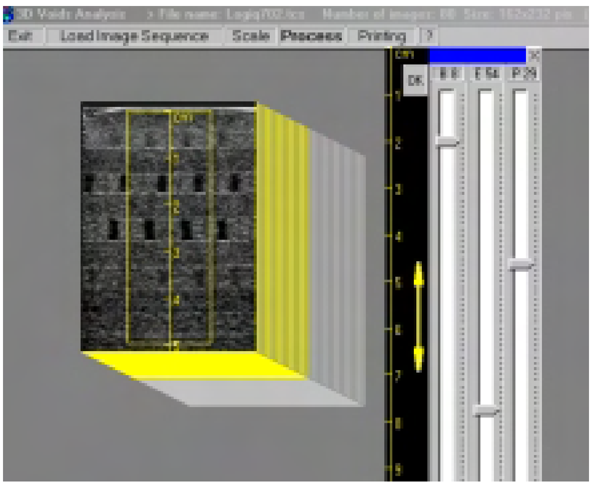

Fig.2. 3D-Void Analysis Program

The selection of the image fragment shown in the **red frame** will be stored as a sequence of images. The settings of the image number and images/sec are available. With

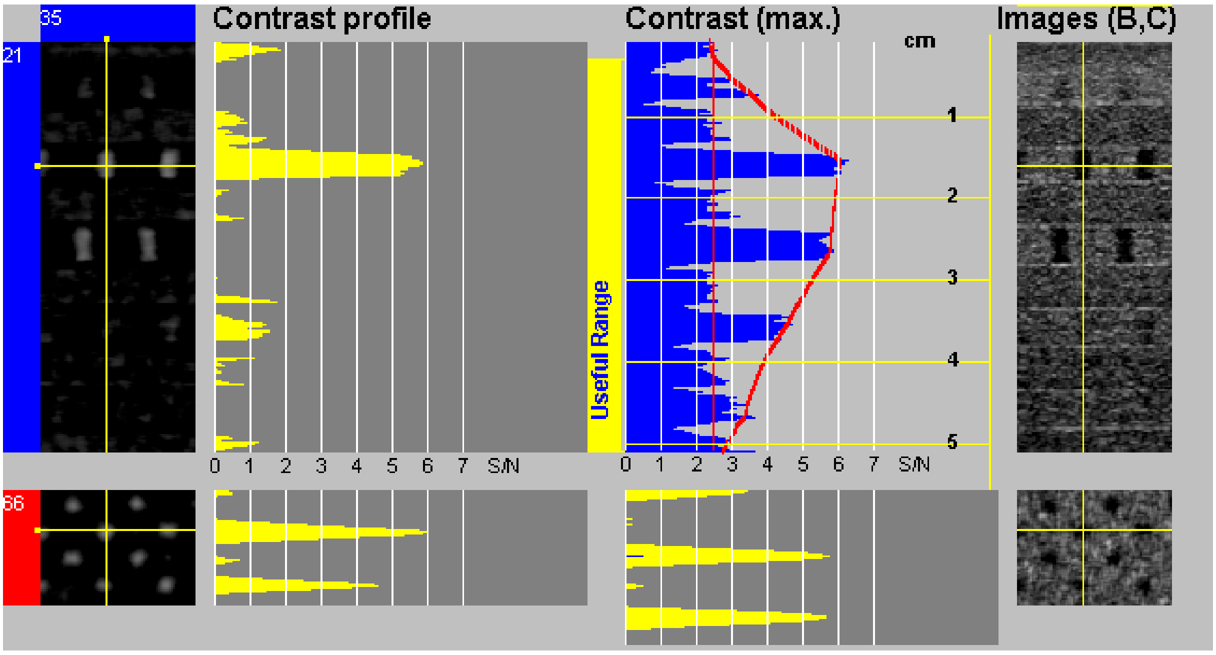

Fig. 3. “Dynamic” presentation of results.

the scale adjustment is the pixel size controlled in order to get the cube pixels shape (voxals).

The image sequence will be compressed in a **volume image** (*.TCS file).

The volume image can be processed immediately using a “3D-void analysis” program and a TCS files, Fig 2.

The adjustment of the 3D-ROI will be performed by using the mouse interactively. The processed image deliver the result in the B- and C-image sequence. These sequences are accessible by “dynamic” presentation, Fig. 3.

In the dynamic presentation there is the accessibility of the sequence of B-images, C-images, contrast B-images, contrast C-images and the gray level profiles inclusive maximum contrast profile graphics. The contrast value can be found dynamically for all voids inside of the volume ROI. The assessment of the maximum depth visualization is unnecessary. It is obvious that any information from the range, where the largest voids are not visible is not reliable. The best optical overview about the scanner contrast ability delivers the C-image. The dynamic presentation of the resulting data allows the seeing of the C-images, the C-contrast images and the gray level profiles of the phantom in all depths.

Instead documenting the quality assurance sheet with accessed data, more images from the “dynamic set” may be printed as a quality document.

Quality Assurance Worksheet

Ultrasound instrument description (producer, type, ser. no.):

Phantom type:

Transducer description (single element, linear array…):

Hard copy image quality (black-to-white transition):

Discrepancy (hard copy versus monitor):

Alphanumeric Character (sharp, ghost free):

Gray level dynamic distribution (if measured):

Maximal spatial resolution (in mm):

Spatial contrast resolution (S/N versus depth):

TOLERANCES OF MEASURED QUALITY PARAMETERS

The results may be qualified as consistent, as long as the image TGC is properly adjusted. This means that the average gray level of the image is depth independent. The not properly adjusted TGC cannot be successfully corrected by subsequent processing if the dynamic curve of the ultrasound instrument is not known [2]. If the TGC is properly adjusted, calculated contrast values are independent from the scanner dynamic setting. With a dynamic setting change, changes in the same sense speckle noise and ratio S/N stay constant.

Unfortunately it always exist the possibility of a wrong scale setting. The wrong scale settings are visible in the image of the voids arrangement in the C-image and in the "mismatching " of the scale with the phantom slices in the B-image.

The "biasing of the results" due to the phantoms geometrical arrangement, caused by non-rigid geometry of soft phantom slices may not be expected. The differences in the contrast, although of the same size, are given by the non-replicable position of the scatterer in the void surrounding. The voids have only globally the equal size. Voids of smaller dimensions show larger differences in contrast to voids of larger size. It is in agreement with void size – scatter density relation. The mathematic models of phantoms and phantom images show the equal behavior.

CONCLUSION

In order to avoid the subjective quality assessment of ultrasound instrument it is necessary to use adequate phantoms and image processing. The measurement automation help to reduce the influence of subjective factors, although it is not possible to exclude these factors totally in such measurements.

The redefinition of quality parameters was necessary in order to avoid misleading and pretending. Independent from the used scanner type, the ultrasound cannot be considered, as a 2D appearance. It is always 3D and the adequate 3D phantom targets must be used to find out the manifestations of the complex 3D beam. The scanner beam shape, which determines the image quality, must be identified and recognized in all of its very fine details.

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