A new method of sonograph lateral resolution measurement using PSF analysis of received signal

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Abstract. *A number of quality parameters of ultrasound image have been defined. Their objective and accurate measuring, however, is relatively difficult. This is why we have developed a complex system, based on the point reflector principle, which enables us to analyze the point spread function (PSF) and measure this way a number of significant image quality parameters at any point of the area being imaged.*
A measuring system was designed and a program was developed for evaluation of lateral spatial resolution (LR) by 6dB drop method, enabling measuring of this parameter in a defined image area with any step of object shift in space, adjustable from 0.01mm.
By this method, we are able to determine LR numerically and accurately at any point of the area being imaged by sonograph. It enables us to image this function by three-dimensional graphics, including basic statistical measuring parameters. The method is a significant part of the complex of measuring of qualitative sonograph parameters which will be introduced by the Czech Metrology Institute within statutory regular quality control of specified medical equipment in the Czech Republic.
Keywords: *ultrasonography, PSF analysis, lateral spatial resolution*

1. Introduction

The goal of our work is the development and practical evaluation of an objective measuring method for ultrasonograph imaging quality assessment. This complicated problemmatique was resolved using Point Spread Function (PSF) analysis of the received signal from which a numerical value is derived. This expresses a parameter of the Lateral Resolution (LR), judged to be of paramount importance for image quality description. .

We devised our own original construction of the measuring system to evaluate the method and measurement procedure.

2. Methods

Ultrasonography (US) is the most used diagnostic imaging technique in medicine. For diagnosis, the quality of the image is most important. This parameter is very complex and difficult to measure. Its chief measurement is resolution, which has three basic levels of complexity – time, spatial and contrast resolutions. Time resolution has importance only in dynamic processes, whereas spatial and contrast resolution determine the quality of all imaging modes. Measuring contrast resolution is not a technically difficult task. By contrast, evaluating spatial resolution (SR) is very difficoult. Three spatial resolution axes have been defined in the case of SR, namely, axial (AR), lateral (LR) and (TR) transverse (elevation). All three are important for image quality. Axial SR depends on wavelength and transmitted pulse duration and, is relatively stable over the scanned area. On the other hand lateral and transverse SR depend on a number of other technical parameters of the measured sonograph and transducer. They can, from time to time, deteriorate due to technical defects or instability of the technical parameters of the sonograph and/or transducer. The last two named play a greater role in the image quality than the axial SR. For this reason it is vital to find a way to measure them accurately. Two basic methods are commonly used in this regard. If the tissue mimicking phantom method is used, the results depend on the subjective evaluation of the observer. Alternatively, signals to noise ratio methods of analysis are used. Both methods are able to detect or test for a number of malfunctions but their drawbacks are subjective evaluation in the first case and in the second, impossibility of precisely determining the defect location and ultimately its origin.

In our institute we designed and devised equipment, which maps a defined space in the scanned area with the help of a sphere reflector and evaluates from the sonogram, a Point Spread Function from the received signal. This measurement method makes it possible to determine numerical parameters corresponding to axial, lateral and transverse resolutions. Evaluating their distribution over the scanned area enables us to acquire infomation on the spatial distribution of the errors of the SR, in the Lateral, Transverse and Axial directions.

It is also possible to detect errors and nonhomogeonity in dynamic focussing, time gain compensation, digital processing. Finally, it can be used to evaluate at the side lobe level.

3. Principle

The basic principle is as follows: the measured sonograph scans a small metallic ball target that moves in a water bath on a specified trajectory. The bath is filled with degassed water mixed with ethylalcohol and the walls are fitted with absorbent material. The positioning system has a ball target holder, designed according to instructions given in the IEC 854. The ball target consists of a small steel sphere, a laser welded to a tiny platinum wire which is fixed in the holder. The shape of the wire ensures that the sphere is oriented in front of the transducer in the scanned plane with the welding point in the distal position. The platinum wire is hard enough to eliminate any movement of the ball target during replacement in the water bath due to hydrodynamic forces. 3D positioning is arranged by three stepper motors connected to precise support screws. The motors are driven by a computer controlled power unit. The video signal from the test US scanner is driven to Frame Grabber NI PCI-1411 (National Instruments), digitalized and the Region Of Interest (ROI) is stored after on-line evaluation. The system selects the video frame containing the peak amplitude for each measurement point in the scanning plane to derive the PSF function in a lateral direction centered in the pixel with the maximum amplitude. The PSF in the axial direction is obtained by the same procedure. A different method is used to record the transverse resolution. The distribution of maximum echo pixels in ROI during vertical movement of the reflection ball is recorded from each frame.

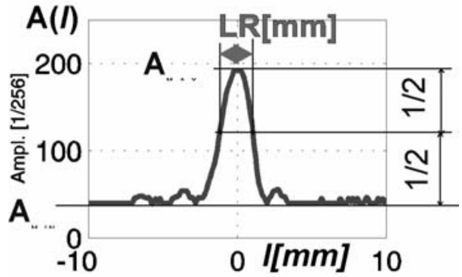

Figure 1. The LR calculation from PSF

To calculate the Lateral Resolution (LR) we analyse the PSF in the lateral direction. As LR we take the width of the amplitude peak in one half of the amplitude and recalibrate for the actual amplitude level. See Figure 1.

Values A+LR (l+) and A-LR (l-) are found for the following conditions:

l+ > 0   and l- < 0

$$A_{\pm LR} = \frac{A_{MAX} + A_{MIN}}{2} \qquad [1/256]$$

We can then express the LR corrected for difference between measured maximal amplitude AMAX and maximal possible amplitude 255 digitalisation units

$$LR = \left(l_{+} - l_{-}\right) * \frac{255}{A_{MAX}} \quad [mm]$$

AMAX is a peak amplitude in PSF

AMIN is minimal signal amplitude level in PSF (back ground noise level).

To date we have been able to plot the LR characteristic over the scanning plane. This can differentiate separate scanning lines and even multiple focal areas for dynamic focussing systems (see Figure 2 and Figure 3.)

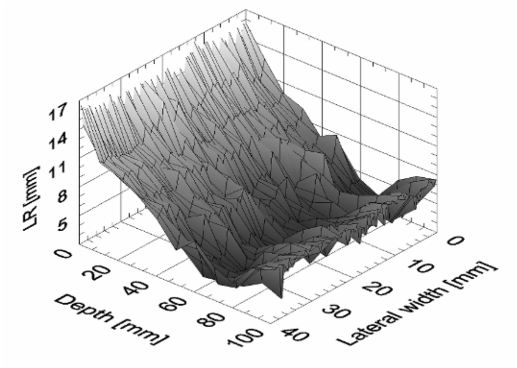

Figure 2. LR characteristic of a linear 3,5MHz transducer, using one focal point at 10 cm depth.

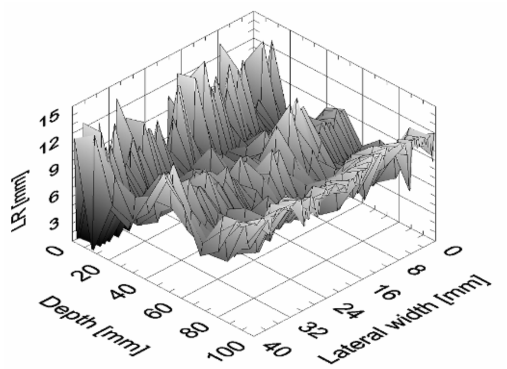

Figure 3. LR characteristic of a linear 3,5MHz transducer, using two focal points at 5 and 10 cm depth respectively.

The results depend on adjustment of the following parameters of the measured sonograph:

Gain and Time gain Compensation, Transmitted Power (MI), Dynamic Range (contrast), Preprocessing and Postprocessing settings, Smoothing, Correlation and Output Video-signal Level. All these parameters are adjusted to their optimal settings and the adjustment parameters are stored. This is the only way to obtain valid and comparable results.

Currently we are working on accurate side lobe estimation. Our measuring system can detect malfunctions in dynamic focussing, size of aperture, time gain compensation function and/or transducer element failure.

4. Results

We have measured 6 sonographes of varying technical standard equipped with one or more transducers - linear, convex or sector scan. We have done more then 80 single and repeated measurements for determining reliability, accuracy and reproducibility during the year 2004.

We have also measured defective transducers.. Figures 3a,b,c show a case where a faulty linear transducer 5MHz was measured. The most notable effect was on the received echo amplitude inhomogeneity and suppression, LR deterioration and focus area disappearing. The transducer had a defective cable with a few wire lines interrupted. In another case we found unequal gain in input channels when an area of higher and lower amplitude of received signal was alternating. None of these findings has been reported for conventional measuring methods.

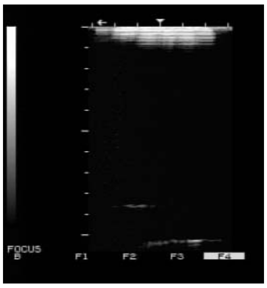

Figure 3a. The B-scan picture of the ball target scanned with defective transducer 5MHz at depth cca 10 cm, using one focal point (F4).

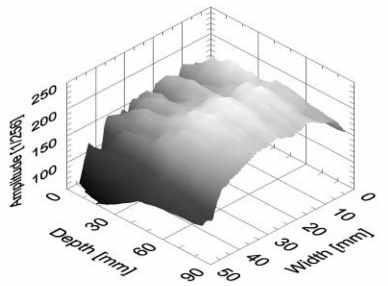

Figure 3b. The amplitude characteristic of the transducer, measured in an area 50x90 mm .

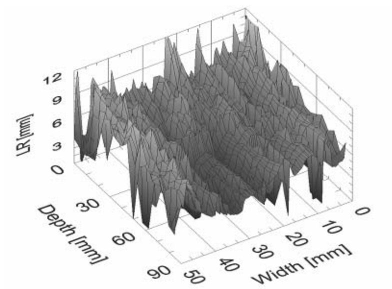

Figure 3c. The LR characteristic of the transducer, measured in an area 50x90 mm .

5. Conclusions

We found that our equipment gives sufficiently accurate and objective results. We have ability to detect faults which other measuring methods are not able to determine such as errors in dynamic focussing, uniformity in gain setting in lateral and axial directions, malfunctions of the dynamic aperture settings and dropouts of elements in electronic transducers.

This method is not as easy or as fast to use as tissue mimicking phantoms or 3D signal to noise ratio evaluation, but it provides accurate and objective numeric parameters corresponding to the quality of imaging at any specified point over the whole scanning area. It is also a very powerful tool particularly in combination with the other methods mentioned above.

Acknowledgments

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