A NEW APPROACH TO AN ULTRASOUND IMAGING SYSTEM EVALUATION USING THE POINT SPREAD FUNCTION

L. Doležal, J. Mazura, J. Tesařík, J. Hálek, H. Kolářová,

Faculty of Medicine/Dept. Medical Biophysics, Palacký University, Olomouc, Czech Republic

ladol@tunw.upol.cz

Abstract: A complex system based on the point reflector principle has been developed to analyze the Point Spread Function (PSF) and in this way measure a number of significant image quality parameters at any point in the area being imaged. Our system uses digital image analysis for accurate and objective measurement. To date we have been able to plot the Lateral Resolution (LR) characteristics over the scanning plane. This can differentiate separate scanning lines and even multiple focal areas for dynamic focusing systems. Our measuring system can detect malfunctions in dynamic focusing, size of aperture, time gain compensation function and/or transducer element failure.

Introduction

Problems related to the safety of ultrasound application have predominated the more than 50 years of ultrasound use in medicine. The direct effects of ultrasound energy on living tissue have been the main focus for a considerable time. On the other hand, the danger inherent in the possibility of incorrect treatment resulting from erroneous diagnosis based on misinterpretation of the sonogram has only been taken into consideration in the last decade. Misinterpretation is possible owing to artefacts. These may affect ultrasound diagnosis and treatment where wrong treatment based on faulty interpretation of the image may cause patient harm. When evaluating the risks of such artefacts, it is necessary to differentiate objective and subjective factors.

a) Objective risk factors include:

Imaging physical artefacts, inadequate *quality of equipment imaging* caused by low technical standards, poor maintenance or age of equipment.

b) Subjective factors relate to the skills of the examiner. These include:

Unfamiliarity with the physical mechanisms of ultrasound image creation, lack of skills in operating the equipment and hence inability to set the optimal working parameters, lack of knowledge of the topographic anatomy necessary for correct image interpretation, inborn characteristics of the observer such as spatial imagination and the ability to abstract what is seen.

Physical artefacts are based on the physical properties of ultrasound waves and the environment in which they are propagated. As such they are unequivocally definable according to physical laws and to eliminate them, it is necessary to apply appropriate procedures and imaging methods. If these do not exist, the physical laws must be accepted and taken into consideration. In this case eliminating the risks is totally dependent on the experience of the examiner and the above mentioned subjective characteristics.

On the other hand, the sonograph imaging quality is a factor completely dependent on the technical parameters of the equipment. In order to increase the imaging quality or eliminate imaging defects and thus reduce the risks mentioned, it is necessary to create a system for determining and objectively evaluating the relevant qualitative parameters [1].

This is very difficult and requires definition of the parameters of sonographic imaging quality, development of suitable measuring methods, procedures for their evaluation and the creation of a graded system of sonograph quality criteria.

Some international standards and recommendations have been introduced over the last decade and commercial testing objects for B-mode imaging are being produced. These contain defined non-homogeneities and the image is analyzed subjectively. To fulfill all important physical criteria for correct mimicking of the tissue [2], the construction has to be rather sophisticated. The testing method is fast and relatively inexpensive, but it is, however, burdened with a large error resulting from subjective assessment of image quality, even with the use of computer technology.

Another very interesting method [3] utilizes spatial analysis of the signal/noise ratio in a three-dimensional image of a special testing object to create the image characterization for signals with small amplitude. This method is suitable for fast orientation measurement and is substantially more objective than the ones mentioned earlier. Its only disadvantage is that it shows an integral parameter which is dependent on depth and cannot therefore determine the lateral details of the image defect. Also, analysis of spatial image distortion and characterization of the system for high amplitude reflected signals is not possible. These methods are primarily suitable for in situ screening studies. They are not time consuming which is important where there is heavy equipment workload. They do not, however, produce detailed objective information.

ISSN: 1727-1983 © 2005 IFMBE

Another type of measurement that can be used for analyzing sonograph qualitative parameters is measurement of characteristics of the radiated ultrasound field. This however, does not evaluate the image quality. It only determines the parameters of the actuating ultrasound signal and is suitable mainly for controlling the radiated ultrasound intensity, or, possibly, its space and time stagger, which is significant for maintaining allowed limits and for assessment of the effects of ultrasound energy at various types of tissue borderlines. Additionally, there are mathematical models of the ultrasound field radiated by certain types of probes [4] and its heat effects.

It is obvious that quantitative and accurate evaluation of the imaging quality is very difficult and, internationally, there are few institutes that deal with the problems using the methods mentioned above.

The aim of our research was the development and evaluation of an objective measuring method for ultrasonograph imaging quality assessment with the capability of providing numerical measurement results and localising spatial image defects. This complicated problemmatique was solved 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 constructed our own original measuring system for this purpose.

Materials and methods

The Point Spread Function is defined as a function which describes the shape of the image produced on the detector by a delta function δ(x) (point) source [5].

The application principle of the definition 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 ethyl alcohol and the walls are fitted with absorbent material. The positioning system has a ball target holder, designed according to IEC standard [6]. The ball target consists of a small steel sphere, a laser welded to a tiny platinum-iridium 90%/10% 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 wire is hard enough to eliminate any movement of the ball target during replacement in the water bath due to hydrodynamic forces. 3D positioning adjustable from 0.01mm is arranged by three stepper motors actuating support screws. The motors are driven by a computer controlled power unit. The video signal from the test US scanner is driven to a Frame Grabber NI PCI-1411 (National Instruments), 10 bits 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 centred 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.

To calculate the Lateral Resolution we analyse the PSF in the lateral direction. As LR we take the width of the amplitude peak in one half of the amplitude (-6dB level) 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 $l_- < 0$

$$A_{\pm LR} = \frac{A_{MAX} - A_{MIN}}{2} \quad \left[1/256 \right] \qquad (1)$$

We can then express the LR corrected for difference between measured maximal amplitude A_{MAX} and maximal possible amplitude 255 digitalisation units

$$LR = \left(l_+ - l_- \right) * \frac{255}{A_{MAX}} \quad [mm] \qquad (2)$$

A_{MAX} is a peak amplitude in PSF

A_{MIN} is minimal signal amplitude level in PSF (background noise level).

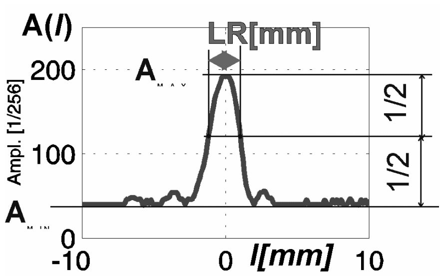

Figure 1: Principal scheme of the LR calculation from PSF

Results

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.

More than 100 measurements of different scanners and transducers were carried out to assess the reliability and accuracy of the method. Even if we use only the LR and echo-amplitude as parameters for the focal zone and uniformity of scanning property characterisation, the information acquired is still accurate and comprehensive .

Samples of different characteristics and corresponding comments on the findings as follow.

Figure 2 shows the typical shape of LR characteristic measured with a linear transducer directed to one focal point using dynamic focussing. The evaluated area was 40 mm wide and 150 mm deep. The position of the focal point F2 (minimum value of the LR) and slight non-uniformity of the LR between scanning lines are distinctive.

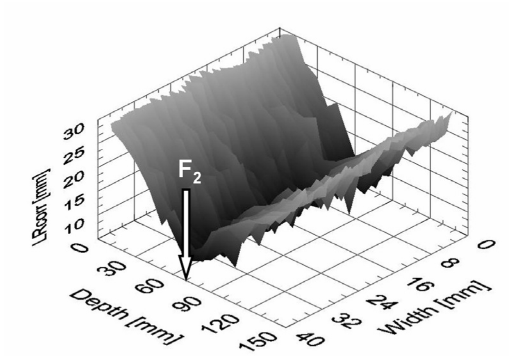

Figure 2: A LR profile of a linear transducer 3,5 MHz in a scanned area 40 mm wide. The improvement of LR in focal area F2 is remarkable

The same transducer's LR characteristic in Figure 3 shows the effect of dynamic focussing. In this case the focal point F1 positioned close to the transducer was switched on. This fact significantly improved LR close to the transducer, while far area persevered unchanged.

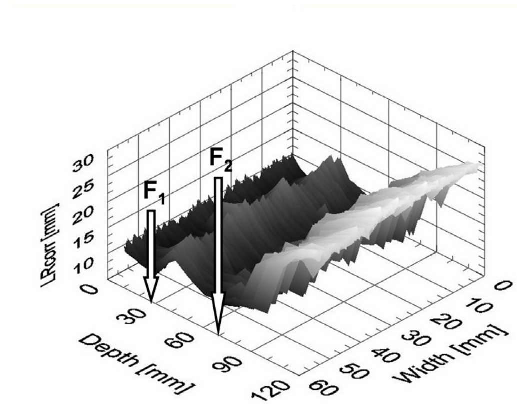

Figure 3: The same transducer as in Figure 2. The scanned area 60 x 120 mm Dramatic improovement of LR in near field is caused by the second focus F1 application

The transducer has been in use for more than ten years in daily practice, its working frequency is 3.5 MHz, scanning area width 107 mm and depth 186 mm. The system enables two points dynamic focusing only.

The echo-amplitude characteristics of the mechanical sector transducer 5 MHz are plotted in Figures 4 and 5. This set shows the excellent possibility of visualising scanning lines by the measuring method. The low line density scanning mode (128 lines per whole scan) in Figure 5 enables plotting of separate ultrasound beams profiles. The lines space given by high line density mode (256 lines per whole scan) is not detectable by the measuring system – see Figure 4.

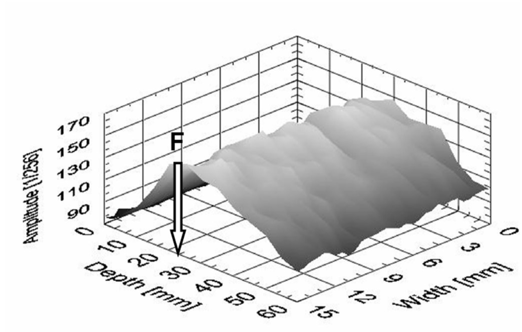

Figure 4: An echo-amplitude characteristic measured over narrow scan area 15 mm of mechanical sector transducer 5 MHz scanning in high line density mode

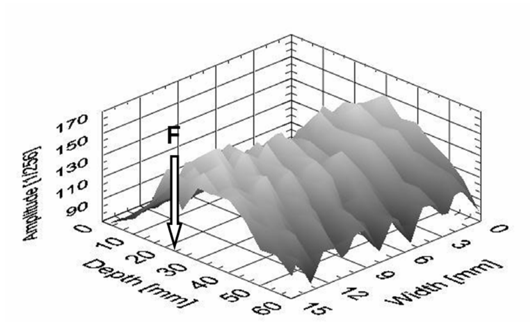

Figure 5: The identical transducer as in Figure 4 scanning in low line density mode. Profiles of scanning lines are visible

The last set of figures introduces application of the measuring method for transducer malfunction detection. A linear 5 MHz intracavitary transducer with defect in the outer side of the acoustic lens was examined over a scanning area 80 mm depth and 30 mm wide. The scanning system used two of four possible dynamic focal points whose position is evident from Figure 6. A malformation of both the echo-amplitude characteristics and the LR due to the transducer defect is manifested in Figures 5 and 6 respectively.

ISSN: 1727-1983 © 2005 IFMBE

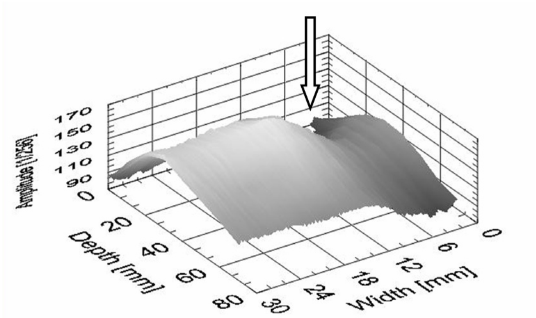

Figure 6: A linear transducer 5 MHz with defective acoustic lens at scanning width 0 – 12 mm. The arrow marks the area where drop in sensitivity is essential. Two focal points are used – see Figure 7

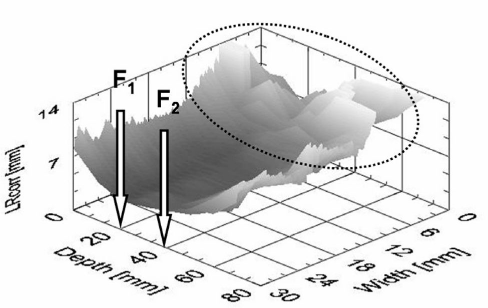

Figure 7: The same transducer as in Figure 6. Either LR is affected by the defect (circle marked area). Positions of both focal points F1 and F2 are marked by arrows

Discussion

We are utilising the data collected by this method to date, to continue work on this project. Combined with other ultrasound scanner quality checking methods our system adds another complementary parameter for complex assessment. Promising are a number of other parameters which may be derived using the PSF analysis e.g. transversal profile and side lobes level spatial distribution mapping and/or dynamic focusing malfunctions, crystal dropouts and time gain compensation function failures.

The method is not suitable for low level contrast resolution estimation or scattering noise level determination or other methods of soft tissue resolution measurements. The point reflector used is a high reflective target which is mostly suitable for technical measurement.

This method is not as easy or as quick to use as tissue mimicking phantoms or 3D signal to noise ratio evaluation methods. However it provides accurate and objective numeric parameters corresponding to the quality of imaging at any specified point over the whole scanning area.

The method referred to may serve as complementary to the complete set of test procedures which should be used for effective and reliable ultrasound scanner quality assessment urgently needed by health service systems.

Acknowledgements

This study was supported by grants of the Czech Ministry of Education, Youth and Sports, the project KONTAKT No: 1P2004ME720 and the project AKTION No: 2005-28.

References

[1] ALASAARELA, E., KOIVUKANGAS, J.: ‘Evaluation of image quality of ultrasound scanners in medical diagnostics’, *Journal of Ultrasound in Medicine.* **9**, pp. 23-34

[2] KOLLMANN, CH., BERGMANN, H., TRABOLD, T., ZOTZ, R.:’Ein Testobjekt zur Qualitätssicherung von 3D-Ultraschalgeraten’ *Z. Med. Phys.* **11**, pp. 45-52

[3] SATRAPA, J., DOBLHOFF, G.:’Automated quality control of diagnostic ultrasound appliances’, *Ultraschall in der Medizin* **23**, pp. 123-128

[4] ROZMAN, J., OREL, D., VÁCLAVÍK, V. et al.:’Modelová studie vyzařování ultrazvukových sond’, in ’Report on project of Czech Grant Agenture ČR č. 102/00/0936’, (VUT in Brno, 2002, ISBN 80-214-2289-0)

[5] Internet site address: http://hea-www.harvard.edu/AstroStat/astrojargon.html, 28.8.2005

[6] IEC 61391-1 ’Ultrasonics – Pulse echo scanners – Part 1: Techniques for calibrating spatial measurement of system point spread function response’, (In preparation stage).