ISSN 1392-2114 ULTRAGARSAS (ULTRASOUND), Vol.66, No.1, 2011.

The scanning algorithm suitable for the arbitrary construction arrays

R. Kažys, L. Kairiūkštis, A. Voleišis, R. Raišutis

Ultrasound Institute, Kaunas University of Technology

Studentų 50, 51368 Kaunas, LITHUANIA, Phone: +370 37 351162, Fax. +370 37 451489,

E-mail: ulab@.ktu.lt

crossref http://dx.doi.org/10.5755/j01.u.66.1.262

Abstract

This paper explores the scanning algorithm which can be employed in non-destructive testing and medical investigations where arrays are used. Nowadays the testing systems are equipped with very high speed processors and data transfer systems but sometimes the systems are limited by the used power and the amount of data transmitted from system. So using a smaller number of excitation sequences the arrays systems can be exploited in the application where power consumption or the bandwidth of the transmitted media are critical.

The data collection method for the ultrasonic array was described in the previous studies [5]. To prove the proposed data collection method the experiments were carried out. The algorithm allows us to use a minimum number of the exited elements of the array, while the scanning resolution can be the same like in the single point focusing case.

Keywords: phased arrays, simulations, ultrasonic field, scanning algorithm.

Introduction

Ultrasonic arrays are widely used in sonar applications, medical, seismic systems and non-destructive testing. Arrays used in non-destructive testing and medical applications vary in shape. Construction of the array is adapted to specific area of the investigation. The constructions of the arrays and performance dependencies upon geometrical dimensions are studied widely [1] except the cylindrical array, because these types of arrays are not so often met. One of the major advantages of the cylindrical array is that the beam can reach any arbitrary point around the probe, so such arrays are very practical for investigation of objects with an axial symmetry. The main shortcoming of such arrays is limited focusing possibility due to cylindrical geometry of arrays.

The investigation of the focusing possibilities of cylindrical and convex arrays showed us the limited focusing possibilities of the array. We studied acoustic field of the relatively small (height L=5mm, diameter D_{max}=13,4 mm) cylindrical phased array which has 128 elements [2]. Such relatively small arrays may be used in the endoscopic ultrasonography. In this case wireless ultrasound capsule will be moving in the gastrointestinal tract by natural peristaltic movements of the stomach and intestines collecting ultrasonic data on its way [3]. The wireless capsule use energy for exiting elements of the array, capture and transfer images outside the body, so the power consumption is very critical task for the engineers. The resolution of the inspected object using arrays mainly depends on the number of scanning sequences, so we always deal between the quality of the received image and the used power.

To find the optimum numbers of scanning sequences, the simulations were performed in a homogenous medium - water at several frequencies from 2.25 MHz to 7.5 MHz [2]. Beam width versus the focal distance with a different number of active elements for chosen focal distance was simulated. The focusing efficiency of the cylindrical array the beam width of the main lobe was calculated at -6dB and -12dB levels while the array is operating in a transmission mode. The influence of the array active aperture size to the beam width was analyzed and construction of a cylindrical phased array was optimized and these data was used in the development for the scanning method for the cylindrical array [4].

Despite computing speeds of the data processing are increasing drastically, sometimes is not possible to use the process images in the real time due to huge amount of the analyzed data. In the previous works we investigated the ultrasonic array which has up to 128 elements [2]. Such array generates at least one hundred times more data in comparison to monolithic transducers, so it is challenge for acquisition system to handle such amount of the data while working in real time applications. To solve this problem, the scanning method for the cylindrical array was offered [4]. To determine steps of the scanning sequence, ultrasonic fields of the cylindrical array were simulated while number of exited elements and the focal point varies. The width and the length of the main beam lobe at the arbitrary focal points were calculated, while the ultrasonic beam is focused or steered. The investigation answered the question to what extent we can steer focused beam and how the beam steering influences resolution and scanning time, while the distance of reflectors from the probe is not a constant. The offered scanning method is suitable to use with convex and cylindrical arrays for the investigation of objects which have the axial symmetry with the same probability around the probe.

The scanning sequence described in the previous work [4] is useful in a time consuming approach while performing scans without a priori information about inhomogeneities around the probe. The provided algorithm allows scanning around the probe with a fixed spatial resolution at any arbitrary point in the region of the investigation. The fixed lateral resolutions can be achieved by varying the number of exited elements, while the focus distance z_f can vary from 5 to 40 mm from the probe surface. After simulations we found that the beam steering is undesirable for the arrays with a cylindrical geometry, but can be used for certain tasks taking into account limitations arising from the steering angle. To maintain a high speed of the inspection only the beam focusing was chosen in the scanning sequence but the beam focusing using variable aperture of the probe is not good enough for the low power systems.

To maintain a low power consumption and small amount of data analyzed, we should minimize the number of shots made by the array. To get steered or focused beam phased arrays employs emitting and receiving delays laws. The main thing is that in the scanning sequence which we have used in our simulations (Table 1) and experiments, we did not use any delay laws. We collected all necessary data in number of steps which is equal to a number of array's elements.

In this paper experimental results of the proposed fast scanning algorithm are presented.

Experimental setup

The experiments were carried in a water tank with the ultrasonic measurement system, which has been developed and manufactured at Ultrasound Institute of Kaunas University of Technology (UI KUT) (Fig.1.).

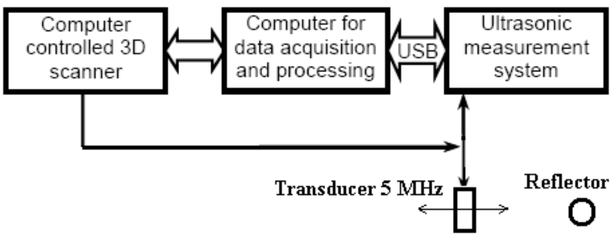

Fig.1. **Structure diagram of the experimental system**

The "virtual" array concept was used in the experiments. The reflector attached to the support device (Fig.2.) had fixed coordinates and the element of the array (Fig.3.) was attached to the arm of a precise mechanical scanning unit, so the different positions from the reflector was achieved by one monolithic transducer.

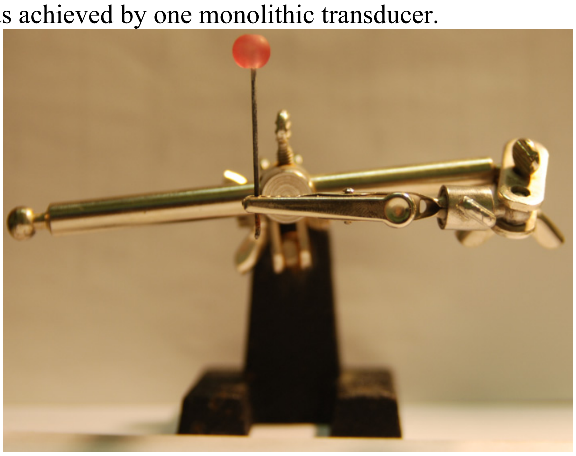

Fig.2. **Support device with target used in experiments**

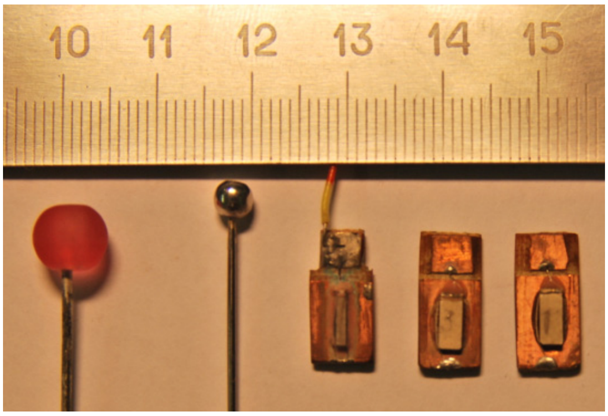

Fig.3. **Targets and transducers used in experiments**

The brief description of the "virtual" array concept is that we can measure the performance of the array which has unlimited number of elements if each element works only in a pulse-echo mode. In our case, the ultrasonic transducer was moved in x direction during scanning process with steps equal to the width of the element what corresponds to the pitch of the real array. We imitated 4, 8 and 16 elements arrays. The measurements were performed with the spatial scanning steps of 5 mm in y direction in order to imitate different distances from the reflector. As soon as the scanning sequence (Table 1) is executed and data are collected, we can start processing of the A-scans.

Table1. **The scanning sequence matrix for N elements array used in experiments.**

Sequence	Element number which emits	Element number which receives
1st	1st	1st
2nd	2nd	2nd
………	………	………
N+1th	N+1th	N+1th
Nth	Nth	Nth

The collected signals can be viewed at different time lags. By comparing the time of flight we are able to determine the position of the reflector along x and z axis. At this step we can reconstruct the image for arbitrary depth within limits by scaling the signal in the time axis. To reconstruct the reflector coordinates we used the Kirchoff migration technique, which is known from the field of seismic investigations [5]. According to the migration technique the location of a circular wave front at the time instant t can be found:

$$c^2t^2 = (x - x_0)^2 + (z - z_0)^2 , \qquad (1)$$

where c is the speed of sound in medium, t is the travel time from the emitter to the reflector (defect). Lets say that the array element (receiver) is at the position (z_0, x_0) where z_0= 0 and the coordinate x_0 varies depending on a array elements center position. The distance z is equivalent to the radius of the circle:

$$z = \sqrt{c^2t^2 - (x_i - x_0)^2} \qquad (2)$$

Table 2. **Collection's of time of flights which correspond to different elements of the array used in scanning sequence**

	Time t_1, μs				Time t_2, μs				Time t_n, μs			
	Amplitude, dB				Amplitude, dB				Amplitude, dB			
z_1	x_1	x_2	…	x_n	x_1	x_2	…	x_n	x_1	x_2	…	x_n
z_2	x_1	x_2	…	x_n	x_1	x_2	…	x_n	x_1	x_2	…	x_n
…	…	…	…	…	…	…	…	…	…	…	…	…
z_n	x_1	x_2	…	x_n	x_1	x_2	…	x_n	x_1	x_2	…	x_n
z_{n+1}	x_1	x_2	…	x_n	x_1	x_2	…	x_n	x_1	x_2	…	x_n

So for each element position (z_0, x_0) we can get the time of flight and the amplitude (Table 2). We should analyze time of flights in the time lags (t_1, t_2..., t_n), because we do not have preliminary information about reflectors and theirs locations (distances from the elements of the array). By solving Eq.2 for a particular time lag, we draw circles where intersection of the circles arcs will show the reflector position.

Experiment for determination coordinates of the reflector using the array of 8 elements

For testing of the proposed data collection and processing algorithm the 8 elements ultrasonic arrays were selected. The transducer with the following dimensions was used (Fig. 3): the active aperture W=5mm, the element width e=2mm. The excitation voltage of 10 V at 4.75 MHz central frequency was used. The duration of pulse τ =10 μs.

The probe was placed in a coupling medium – water (c = 1483 m/s), so that the coordinates of the center of the active aperture are z = 0 mm and the x = 25 mm. The coordinates x_0 which describe positions of the centers of the active elements are given in Table 3.

Table 3. **The x coordinates of the centers of array elements**

x_0,mm							
1st	2nd	3rd	4th	5th	6th	7th	8th
19	21	23	25	27	29	31	33

The spherical plastic (polycarbonate OD2025) reflector with the diameter D=8 mm was placed in water at the fixed distance from the element of the array. The scanner's unit arm with the attached transducer was moving in 2 mm steps along x axis (Table 3) and in 5 mm steps along z axis (Fig. 4). So we have got reflections from the plastic ball at different distances from the array.

To get comparison to conventional ultrasound systems, we took A scans from our experiment and plotted B scan in Fig. 5. The B scan was obtained when the probe was moved from 0 mm to 45 mm in z direction assuming that each element of the array works in a pulse echo mode. The total number of A-scans is equal 80. In this case cannot tell a lot about object at his position, as we can see in Fig. 5.

To determine better the position of the reflector we collected the time of flights from each element at different distances from the reflector. The A-scan from the 5th element of the array is plotted in Fig. 6. It represents reflections from plastic ball while distance from the

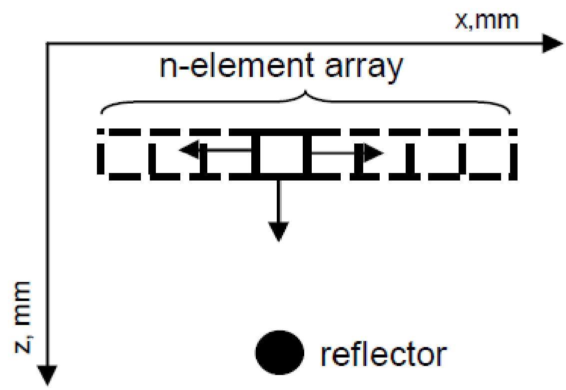

Fig. 4. **Array and target setup. Reflector is at the fixed position, while element of the array moves in x and z directions**

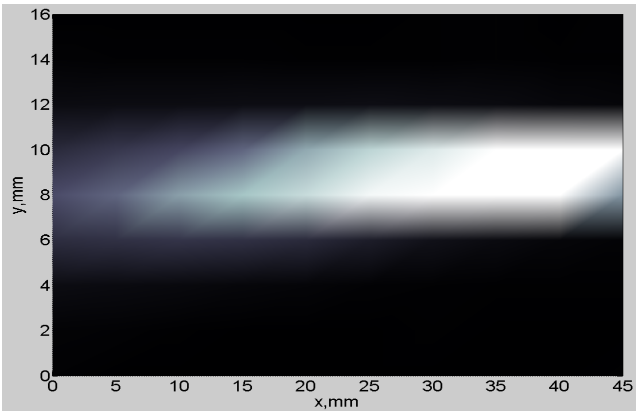

Fig. 5. **B-scan accumulated from 8 element array while elements operating independently in a pulse echo mode**

center of the array (z=0 mm; x =25mm) varies from 0 to 45 mm in z axis. The total number of A-scans is equal 10 per element. It is very important to select appropriate time lags when the time of flight is measured, anyway we can miss a valuable signal. The marks (1-10) on A-scan (Fig. 6) represent reflections from the plastic ball when distances from it to the element of the array vary from 0 to 45 mm.

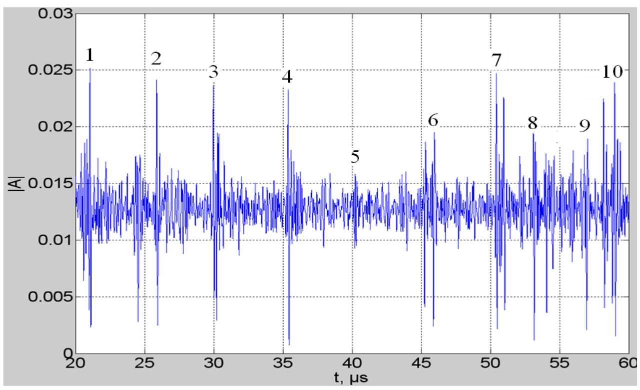

Fig. 6. **A-scan while 5th element is emitter and receiver**

After we got the time of flights for each array element at the certain time instant, we solved Eq. 2. The circles were drawn for each scanning sequence, which define the center and the radius of the circle. The intersection of the different circle arcs shows the position of the reflector in (x ,z) domain. Each circle corresponds to a certain element of the array. In 8 element array case we draw 8 intersected circles.

The reconstruction of the reflector (D=8mm) which was placed at the 20 mm distance from the center of the array is shown in Fig. 7. Note that: the distance is calculated from the surface of the transducer to the center of the ball. The simulation for the same case is shown in Fig. 8. The dots placed on intersections of the circles show us the boundaries (front) of the plastic ball. The front of the ball is approximated by the line which was obtained from the intersections coordinates which are marked as the points in Fig. 7 and 8.

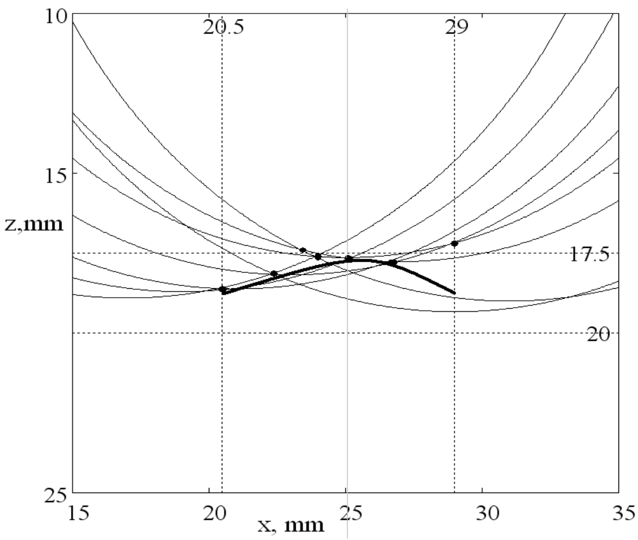

Fig. 7. **Superposition of circles in *x,z* domain shows the coordinates of D=8mm reflector while 8 element array in experiment was used**

The simulation for the 8 element array interaction with the plastic ball is shown in Fig. 8. The differences between theoretical and experimental measurement can be obtained due incorrectly measured the time of flights when the phase of signal changes. To prevent it the A-scans should be converted to echo dynamic curves.

Conclusions

The scanning sequence described above is useful in time consuming approach. This data collection and processing method for arrays allows reconstruction of image for all physically possible angles of incidence without using beam focusing and steering. The proposed method is suitable for arrays with unlimited number of element, but the increasing number of elements in array will increase resolution while we will get more intersections of the arcs of circles, so the curve which is drawn on the top of intersections will approximate the position of a reflector better. To test the method, the reflectors were placed at different distances from the array. The proposed scanning sequence has limitations in the case of multilayer structures where the speed of sound changes per layer and wave form changes as it travels back to receiver. The mentioned limitations can be solved if we will analyze A-scans in fine time lags.

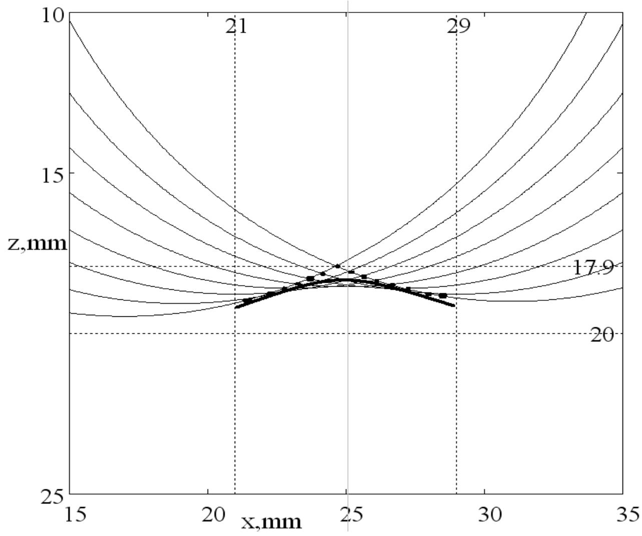

Fig. 8. **Superposition of circles in *x,z* domain shows the coordinates of D=8 mm reflector while 8 element array in simulation was used. Reflector center was at distance 20 mm from the middle element of the array**.

References

1. **Shi-Chang Wooh, Yijun Shi**. Influence of phased array element size on beam steering behaviour. Ultrasonics. 1998. Vol. 36. P.737-749.
2. **R. Kažys, L. Kairiūkštis.** Investigation of focusing possibilities of convex and cylindrical phased arrays. ISSN 1392-2114. Ultragarsas (Ultrasound). 2008. Vol. 63. No.4. P.46-51
3. **E. Jasiūnienė, R. Kažys, L. Mažeika.** Ultrasonic fields of radial ultrasonic array. ISSN 1392-2114. Ultragarsas (Ultrasound). 2007. Vol. 63. No.2. P.44-50.
4. **R. Kažys, L. Kairiūkštis.** Investigation of the complex scanning method for the cylindrical ultrasonic array. ISSN 1392-2114. Ultragarsas (Ultrasound). 2009. Vol. 64. No.3. P.11-16.
5. **G.F.Margrave**. Numerical methods of exploration seismology with algorithms in Matlab.
http://www.crewes.org/ResearchLinks/FreeSoftware/EduSoftware/NMES_Margrave.pdf

R. Kažys, L. Kairiūkštis, A.Voleišis, R. Raišutis

Ultagarsinių gardelių kompleksinio skenavimo metodo tyrimas

Reziumė

Pateikti eksperimentiniai matavimai, patvirtinantys pasiūlyto duomenų surinkimo metodo racionalumą. Tiriant objektą šiuo skenavimo algoritmu, išvengiama būtinybės valdyti ultragarsinės gardelės spindulį. Duomenys apie tiriamąjį objektą surenkami per gerokai trumpesnį laiką negu naudojant daugiafokusį ar sektorinį skenavimą, be to, nenukenčia skiriamoji geba. Tirtasis skenavimo metodas dėl mažos duomenų surinkimo matricos ypač tinkamas sistemose, kurios veikia realiuoju laiku ir yra labai priklausomos nuo energijos suvartojimo. Duomenų surinkimas nereikalauja sudėtingo gardelės ir sistemos sinchronizavimo, nes gardelės elementai apklausiami paeiliui, todėl neveikia vieni kitų darbo. Minėtasis skenavimo algoritmas gali būti pritaikytas bet kokios konstrukcijos gardelės, nebūtinai ultragarsinėms.

Pateikta spaudai 2011 03 22