

METHOD FOR GENERATING A SONAR IMAGE

The invention relates to a method for generating a sonar image of an underwater area by using a sonar carried by a water craft which has a transmitting
5 antenna for radiating sound pulses and a receiving antenna for receiving sound waves back scattered from the underwater area, which spans a receiving sector with a horizontal and vertical sector angle which is covered by at least one directional pattern of the
10 receiving antenna having a predeterminable horizontal and vertical aperture angle.

A known sonar system operating on an ultrasonic basis for generating an image of an underwater area
15 (US 4 288 866) uses sound pulses with a large time-bandwidth product for good range resolution and an image memory which is organized as three-dimensional database of the object reflections. A sound transmitter emits a pseudo random pulse and a sound receiver
20 detects the sound pulses reflected by objects as echo signals. A multi-beam-forming or direction-forming unit, following the sound receiver, which spans a number of beams or directional patterns opened in the manner of a fan in a receiving sector of the underwater
25 antenna outputs a multiplicity of echoes for in each case one cell of angular resolution, the horizontal width of which is determined by the horizontal aperture angle of the beam or the directional pattern, respectively. The echo signals are correlated with a
30 stored pattern of the sound pulse in correlators, at the outputs of which time-compressed pulses are present for cells of angular resolution. An image memory accepts the output pulses of the correlators and generates a three-dimensional database of the echoes in
35 the form of a set of contour lines for each range cell. By means of standard computer graphics technology, an optical image which supports the operator in

identifying an object is generated from the three-dimensional database.

5 A known method for detecting objects buried in the sea bottom (Steven G. Schock ET AL.: "Buried Object Scanning Sonar", IEEE JOURNAL OF OCEANIC ENGINEERING, Vol. 26, No. 4, October 2001 (2001-10), XPO011042612) generates images of line and cable sections which are enclosed in sand. A sonar illuminates a wide strip of
10 sea bottom with a linear array of acoustic projectors and measures the sound back scatter from the illuminated sediment volume with a planar hydrophone array. The output of the hydrophone array is subject to near-field focusing which allows the sonar to operate
15 close to the sea bottom. The near-field focusing reduces the scatter and improves the S/N ratio. A top view and side view of the sea bottom derived from a three-dimensional matrix of focus data supplies the position and the depth in which the objects are buried.
20 An energy detector locates the targets in the focus image data.

To identify sea mines, it is known to combine this so-called broadband sonar transducer technology with
25 signal processing for sound reflection tomography in order to obtain high-resolution images of sea mines from a safe distance of 100 m to 200 m (Brian G. Ferguson "Application of acoustic reflection tomography to sonar imaging", J. Acoust. Soc. Am. 117(5), May
30 2005, pages 2915 to 2928). For this purpose, the water craft carrying the sonar must move around the mine, detected and classified in conventional manner, e.g. by means of a mine hunting sonar, so that the sonar can receive echo signals reflected by the mine from
35 different aspect angles. A two-dimensional image in the shape of the mine is generated from the received echo signals by means of tomographic reconstruction algorithms.

The invention is based on the object of specifying a method for generating a sonar image of an underwater area by means of which a high spatial resolution of the
5 underwater area within the receiving sector of the sound receiver is achieved which is independent of the aperture angle of the beams or directional patterns formed within the receiving sector.

10 According to the invention, the object is achieved by the features in Claim 1.

The method according to the invention has the advantage that an arbitrarily large underwater area can be
15 scanned with high resolution in space so that contours of objects in the underwater area and/or the surface of the bottom of the underwater area are detected with great detail. A virtually straight-line travel of the water craft carrying the transmitting and receiving
20 antenna over in each case one particular route in parallel planes lying above one another is sufficient for this purpose. To simplify the terminology, the traveling plane of the water craft is called horizontal plane and the plane oriented at right angles thereto is
25 called vertical plane. Correspondingly, angles in the horizontal plane, that is to say in the traveling plane, are called horizontal angles and angles in the vertical plane are called vertical angles. The length of the individual routes and the number of routes above
30 one another in parallel are again dependent on the extent of the underwater area to be covered in the direction of travel, that is to say in the horizontal direction and perpendicularly thereto, that is to say in the vertical direction. In the known methods, the
35 spatial resolution of the underwater area in the direction of travel is dependent on the horizontal aperture angle φ , that is to say the aperture angle spanned in the traveling plane, and on the number of

directional patterns or beams in the receiving sector and deteriorates with increasing radial distance. In the method according to the invention, in contrast, the spatial resolution in the direction of travel is
5 independent of the horizontal aperture angle of the directional pattern and constant over distance. It is exclusively dependent on the magnitude of the aspect angle interval covered, that is to say on the horizontal sector angle φ_B of the receiving sector of
10 the receiving antenna, under which equal points of the underwater area are "observed" with the receiving antenna over the route passed by the water craft. The maximum achievable spatial resolution in the direction of travel is generally $\frac{c \cdot \tau}{2} / \sin \frac{\varphi_B}{2}$, where c is the
15 velocity of sound in the water and τ is the pulse duration of the sound pulses. Nevertheless, the number of measuring points, and thus of the aspect angles within the aspect angle interval, must be selected to be sufficiently large.

20 The spatial resolution of the underwater area perpendicularly to the direction of travel, that is to say in the vertical direction, is dependent on the number of routes above one another in parallel which
25 are traveled through by the water craft.

The receiving sector can be spanned by beam forming or direction-forming by a multiplicity of beams or directional patterns located adjacently to one another
30 in the manner of a fan, all of which have the same vertical aperture angle as a result of which, the distance of the measuring points from one another and thus the traveling speed of the underwater craft can be enlarged but the spatial resolution in the direction of
35 travel is not changed. The number of aspect angles under which a volume element in the underwater area is observed is then equal to the number of beams or

directional patterns in which the volume element appears, and can be controlled over the distance of the measuring points. The distance A_y of the measuring points is appropriately selected to be

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$$A_y \leq \frac{\tan \frac{\varphi_B}{2}}{\tan \left(\frac{\varphi_B}{2K} \right)} \cdot \frac{c \cdot \tau}{2 \cdot \sin \left(\frac{\varphi_B}{2} \right)}$$

where K is the number of beams or directional patterns which cover the receiving sector with the horizontal
10 sector angle φ_B .

As an example, a receiving sector of the receiving antenna with a sector angle $\varphi_B = 90^\circ$ shall be assumed which is exposed to sound pulses of pulse duration $\tau =$
15 0.1 ms at a distance A_y of the measuring points from one another. The receiving antenna is assumed to have a beam fan of 10 beams or directional patterns covering the receiving sector which in each case have an aperture angle of 9° . With a velocity of sound $c =$
20 1500 m/s, a spatial resolution of the underwater area in the direction of travel within the receiving sector of 10.6 cm is achieved with these data, independently of the distance. The maximum distance A_y of the measuring points from one another which should not be
25 exceeded is approx. 1.35 m.

In the methods hitherto used in which the angular resolution of the underwater area within the receiving sector is determined by the horizontal aperture angle φ
30 of the beams or directional patterns, in contrast, the same spatial resolution in the direction of travel of 10.6 cm is achieved at a distance of 10 m with a receiving antenna in which a beam fan of about 150 beams or directional patterns is formed with in each
35 case a horizontal aperture angle $\varphi = 0.6^\circ$. To achieve

the same resolution at a distance of 20 m, twice the number of beams or directional patterns with a horizontal aperture angle of $\varphi = 0.3^\circ$ is already needed. To halve the horizontal aperture angle, the
5 length of the receiving antenna would have to be doubled at the same transmitting frequency. This makes it clear that with the method according to the invention, with a sufficiently high traveling speed of the water craft, a high distance-independent angular
10 resolution is achieved with a receiving antenna, the length of which provides a very large margin for attachment also to small, e.g. autonomous or remote-controlled underwater craft. This spatial resolution in the direction of travel is constant and does not become
15 worse with increasing distance - in contrast to the known method. Looked at the other way, using the method according to the invention, a very much higher spatial resolution in the direction of travel than in the known methods, which, in addition, is also constant with
20 distance, is achieved by means of a receiving antenna of conventional length. The method according to the invention also supplies very good image data in close range of the sonar since the curvature of the sound waves at close range is taken into consideration.

25 Suitable embodiments of the method according to the invention, with advantageous developments and embodiments of the invention, are found in the further claims.

30 In the text which follows, the invention will be described in greater detail by means of exemplary embodiments shown in the drawing, in which:

35 figure 1 shows a rear view of a water craft traveling in an area of waters, with a sonar for detecting data from an underwater area, shown diagrammatically,

figure 2 shows a block diagram of the transmitter side of the sonar,

5 figure 3 shows a block diagram of the receiver side of the sonar,

figure 4 shows a perspective view of a three-dimensional analysis space, subdivided into
10 volume elements, in an underwater area, shown diagrammatically,

figure 5 shows a top view of an instantaneous state in the data acquisition in the analysis region
15 in figure 4, shown diagrammatically,

figure 6 shows an enlarged perspective view of section VI in fig. 5,

20 figure 7 shows an illustration for explaining the correlation of volume element and amplitude value of the filter signals with the reconstruction of the sonar image,

25 figure 8 shows an identical representation as in figure 7 according to a variant of the method,

figure 9 shows an example of a transfer function of a
30 filter in the block diagram of figure 3,

figure 10 shows an identical representation as in figure 5 with modified routes to be traveled by the water craft.

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In the method, described in the text which follows, for generating a sonar image of an underwater area, a sonar carried by a water craft 11 is used which has a sound

transmitter 12 (fig. 2) and a sound receiver 13 (fig. 3). The sound transmitter 12 comprises a transmit pulse generator 14 and a transmitting antenna 15 which has a multiplicity of electroacoustic transducers 16 arranged on an antenna carrier. The electrical transmit pulses generated by the transmit pulse generator 14 are radiated by the transmitting antenna 15 as preferably wideband sound pulses in a transmit sector 17, the solid angle of which is at least as large as a receiving sector 18, spanned in the underwater area 10 at the receiving end, with the horizontal sector angle φ_B (fig. 5) and the vertical sector angle φ_Z (fig. 1). The solid angle of the transmit sector 17 exposed to sound from the transmitting antenna 15 is preferably selected to be larger than that of the receiving sector 18.

The sound receiver 13 shown in a block diagram in figure 3 has an electroacoustic receiving antenna 19 of a multiplicity of hydrophones 20 which are also arranged on an antenna carrier. To achieve vertical focusing of the receiving antenna 19, i.e. for setting a vertical aperture angle φ_Z which specifies the vertical sector angle φ_Z of the receiving sector 18, hydrophones 20 located underneath one another vertically are combined to form a so-called stave. Each of the hydrophones 20 shown in figure 3 is thus a part of a stave. All hydrophones 20 or all staves, respectively, are operated simultaneously. From the electrical output signals of the hydrophones 20, group signals are received from different directions of reception with in each case maximum reception sensitivity in familiar manner by signal processing, the so-called direction-forming or so-called beam forming. The maximum reception sensitivity of the receiving antenna 19 is also called the directional pattern or beam. The beam forming is carried out in a beam former 21 or direction-former, producing a fan of

adjacently located beams or directional patterns. In the text which follows, the term beam will only be used in correspondence with normal technical usage.

5 The beam fan (fig. 3) resulting from the multiplicity of horizontally adjacently located beams 22 covers the receiving sector 18 of the sound receiver 13. Each beam 22 has a horizontal aperture angle ϕ (fig. 5) and a vertical aperture angle ϕ_v (fig. 6) which, in the
10 exemplary embodiment described, is made to be equal to the vertical sector angle ϕ_z of the receiving sector 18 (fig. 1). To generate the group signals of the individual beams 22, the output signals of the hydrophones 20 or staves are amplified, sampled with a
15 sampling rate $1/T$ and processed further in complex manner, the individual samples being delayed with the correct timing and added in-phase to form complex group signals. Each of the complex group signals is mixed in complex manner into the base band and low-pass
20 filtered. Following this, the absolute value of the low-pass output signal is formed in block 23. The time variations of the absolute value coming from block 23 will be called received signals in the text which follows. In an alternative embodiment of the method,
25 however, forming the square of the absolute value can also be carried out instead of forming the absolute value. The complex group signals themselves, or their real component, can also be used as received signals for the further processing described in the text which
30 follows, that is to say by bypassing the base band mixing described above and the forming of the absolute value or the square of the absolute value.

In block 24, the received signals are subjected to at
35 least one correction in order to compensate, e.g. for the decrease in the amplitude of the received signals due to geometric attenuation during the forward and reverse travel of the sound pulse. The corrected

received signals are filtered in the filter 25 in such a manner that low-frequency components of the received signals are given lower values than high-frequency components. For this purpose, the filter 25 has a high-pass-like transfer function with a rising, preferably linear variation with frequency. An example of this "high-pass-like" filter 25 is the so-called ramp filter. In the case of the digital signal processing described, a linear system is used as filter 25, the periodic transfer function $H(e^{j\omega T})$ being proportional to the amount of the angular frequency ω within the limits specified by half the negative and half the positive angular sampling frequency $-\pi/2T$ and $+\pi/2T$, respectively, and decreases in the range of $-\pi/2T$ to 0 and rises in the range of 0 to $+\pi/2T$. Such a linear system is shown in fig. 2. The filtering of the received signals as described has the effect that filter signals with positive and negative amplitudes are produced which allow the sonar image to be reconstructed. Further low-pass filtering with a transfer function corresponding to a Si function or a window function, for example with a cosine or Hamming, Hanning or Chebyshev window leads to an improvement in the signal/noise ratio of the filter signal.

To generate a sonar image of an underwater area 10 as can be seen, for example, in figures 4 and 5 diagrammatically in a perspective and top view, a three-dimensional analysis space is defined from a multiplicity of cuboid-shaped volume elements 26 placed next to one another and above one another, which abut one another with their front and side faces, in the underwater area 10. The water craft 11 carrying the sonar successively travels parallel routes 28 which are vertically above one another in the underwater area 10, the vertical coordinates of which are specified by z_k ($k=1$ to L) in fig. 4. All routes 28 are oriented in parallel with the horizontal component y of the three-

dimensional coordinate system x, y, z and are traveled by the water craft 11 in the y direction. The vertical distances of the routes 28 from one another are preferably equal. An appropriate number L of routes 28
5 is obtained from the rough estimate

$$L \geq \frac{z_L - z_1}{\frac{c \cdot \tau}{2}} \tan \frac{\varphi_v}{2},$$

where c is the velocity of sound in water and τ is the
10 pulse duration of the sound pulses (CW pulses) radiated by the transmitting antenna 15. The analysis space is limited by the horizontal coordinates $x_{\min}$ and $x_{\max}$ (fig. 5) in the radial direction, where $x_{\min}$ corresponds to the horizontal distance of the front edge of the
15 analysis space from the routes 28 located above one another. In the y direction and the z direction, the analysis space is specified by the coordinates $y_{\min}, y_{\max}$ and $z_{\min}$ and $z_{\max}$, respectively, which, however, is not shown in greater detail. The cuboid-shaped volume
20 elements 26 in the analysis space have the same base and cover area which is preferably square, and a vertical height Δ_z . The edge lengths of base and cover area are dimensioned in dependence on the desired or maximum possible radial resolution. In the case where
25 CW pulses are emitted, the edge lengths are preferably dimensioned to be equal to or smaller than $c \cdot \tau / 2$. An edge length of greater than $c \cdot \tau / 2$ is possible if the method still described in the text which follows in conjunction with fig. 7 is used for the reproduction.
30 In the exemplary embodiments described here, the edge length is selected to be equal to $c \cdot \tau / 2$. Rough dimensioning of the vertical height Δ_z of the volume elements 26 is obtained from the following equation

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$$\Delta_z \approx \frac{c \cdot \tau}{2} \frac{2x_{\min}}{z_L - z_1}$$

To each volume element 26, a storage location is allocated in a storage medium 27, called memory 27 for short in the text which follows (fig. 3). When the
5 routes 28 are traveled by the water craft 11, the receiving antenna 19 is oriented in such a manner that its receiving sector 18 points to starboard in the exemplary embodiment. In this context, the angle enclosed by the center axis 181 or bisecting angle line
10 of the receiving sector 18 with the longitudinal axis of the water craft 11 is selected to be 90° in the exemplary embodiment. However, it can also deviate from 90° . When routes 28 are traveled, the receiving sector 18 with the multiplicity of beams 22 spanned therein
15 scans the analysis region in a width of $x_{\max} - x_{\min}$ (fig. 1 and 5), wherein each volume element 26 of the analysis space is scanned once by the front side edge 182, in the direction of travel, of the receiving sector 18 and once by the rear side edge 183, in the
20 direction of travel, of the receiving sector 18 from each route 28. At successive, preferably equidistant measuring points 29 along the routes 28 (fig. 5), the transmitting antenna 15 in each case emits a sound pulse with the pulse duration τ . The receiving antenna
25 19 receives the echo signals scattered back from the underwater area 10, which are output by the beam former 21 as complex group signals allocated to the beams 22.

30 The group signals are processed by signal processing means in the manner described above so that a time-discrete filter signal (fig. 7 and 8) is available from each beam 22 as described. With the filter signals of all beams 22, the sonar image is progressively
35 reconstructed from measuring point 29 to measuring point 29 so that a complete sonar image of the analysis space in the underwater area 10 is obtained at the end of all routes 28 traveled by the water craft 11. For

this purpose, spherically curved cuboids 30 (fig. 6) with the radial width $c \cdot \tau / 2$, which are adjacent to one another in the radial direction within the area, delimited by a beam 22 with the horizontal aperture angle φ and the vertical aperture angle φ_v , of the analysis space, called analysis space area in the text which follows, are defined at each measuring point 29, which extend over the cross section of the beam 22 up to the area boundaries of the analysis space area, that is to say up to the upper limiting edges 221, 222 and to the lower limiting edges 223, 224 of the beam 22.

The mean curvature radii of the cuboids 30 are calculated from the discrete time values of the filter signals, taking into consideration the velocity of sound c . The mean curvature radius of a cuboid 30 corresponds to the distance of the center 301 of the cuboid 30 from the location of the receiving antenna 19 and defines the position of the cuboid 30 in the analysis space area. The centering point of the receiving sector 18 is considered to be the locus of the receiving antenna 19. This is illustrated in fig. 7. For example, a front cuboid 30 is defined for a discrete time value $n \cdot T$ of the discrete filter signal and a rear cuboid 30 of the same radial width, which rests against the front cuboid 30, is defined for a discrete time value $(n+1)T$ of the filter signal. As is illustrated in figure 7, the amplitude value of the time-discrete filter signal belonging to the time value $n \cdot T$ and $(n+1)T$, respectively, is assigned to each of the cuboids 30. In the example of fig. 7, the amplitude value $a(n)$ is assigned to the front cuboid 30 due to the time value $n \cdot T$ and the amplitude value $a(n+1)$ is assigned to the rear cuboid 30 due to the time value $(n+1)T$. Each cuboid 30 covers a number of volume elements 26 wholly or partially. For all volume elements 26 which are wholly or partially located within the front cuboid 30, the amplitude value $a(n)$ is

written into the storage locations in the memory 27 which are assigned to the volume elements 26 lying wholly or partially in the front cuboid 30. For all volume elements 26 which are located wholly or partially within the rear cuboid 30, the amplitude value $a(n+1)$ is written into the storage locations in the memory 27 which are assigned to the volume elements 26 lying wholly or partially in the rear cuboid 30, wherein, in each storage location, the amplitude value is added to a memory value already present in this storage location which originates from other beams 22 or from measurements carried out at previous measuring points 29. This is carried out for all radially adjacent cuboids 30 which are then specified by the discrete time values $(n+2)T$, $(n+3)T$ etc. and which are then assigned the amplitude values $a(n+2)$, $a(n+3)$ etc.

However, the amplitude values are not assigned 1:1 to all volume elements 26 within the same cuboid 30 but only in a manner taking into consideration their position within the cuboid 30, for which purpose the amplitude values are weighted before they are written into the memory 27. In this process, the weighting is done in two ways. On the one hand, the percentage by volume of each volume element 26 which is covered by the cuboid 30, and on the other hand the receiving sensitivity of the beam 22 which decreases from the center of the beam 22 toward the upper and lower beam edges 221-224 (fig. 6) are taken into consideration. The process of reconstruction of the sonar image described is carried out for each beam 22 in block 31 in the circuit arrangement according to fig. 3, wherein the volume weighting is carried out in subblock 311 by multiplying the amplitude value with a volume weighting factor and the weighting of receiving sensitivity is carried out in subblock 312 by multiplying the amplitude value by a weighting factor derived from the

receiving sensitivity of the beam 22 via its aperture angles φ , φ_v .

In a variant of the method, illustrated in fig. 8, for
5 assigning amplitude values from the time-discrete
filter signals to the individual volume elements 26,
the distance of the center 261 of the volume element 26
from the centering point of the receiving sector 18 is
determined for each volume element 26 which lies within
10 the area covered by the beam 22, that is to say within
the area of the analysis space delimited by the
aperture angles φ , φ_v of the beam 22, and a time value
 t_0 is calculated with the velocity of sound c from the
distance. From the time-discrete filter signal, an
15 associated amplitude value $a(0)$ is taken with respect
to the time value t_0 . In the example shown in fig. 8,
the time value t_0 is between the discrete time values
 nT and $(n+1)T$. In this case, the amplitude value $a(0)$
for the time value t_0 is determined by interpolation
20 between the amplitude values $a(n)$ and $a(n+1)$. The
amplitude value $a(0)$ obtained by interpolation is
assigned to the volume element 26. This amplitude value
 $a(0)$ is weighted in accordance with the position of the
volume element 26 in the beam 22, and is multiplied by
25 a weighting factor which takes into consideration the
receiving sensitivity of the beam 22 at the location of
the volume element 26. This is carried out for all
volume elements 26 which are located within the area of
the analysis space delimited by the aperture angles φ ,
30 φ_v of the beam 22. The further process proceeds in the
same manner as described, that is to say writing the
weighted amplitude values into the associated storage
locations and adding them to the memory values already
present. The prerequisite for this variant of the
35 method is that the edge length of the quadratic base
and cover areas of the volume elements 26 is
dimensioned to be equal to or smaller than the radial
resolution, which is illustrated in figure 8 by a front

and a rear boundary line and is $c \cdot \tau / 2$ in the exemplary embodiment. An edge length of the volume elements 26 which is greater than $c \cdot \tau / 2$ as in the variant of the method according to figure 7 is not permissible.

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The reconstruction described is carried out at all measuring points 29 along the routes 28 in each case in all beams 22 with uninterrupted, preferably continuous travel of the water craft 11, the measuring points 29
10 having a distance A_y from one another (fig. 5). The maximum distance A_y which should not be exceeded for correct data acquisition is dependent on the number of beams 22 which cover the receiving sector 18 and can be roughly estimated in accordance with

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$$A_y \leq \frac{\tan \frac{\phi_B}{2}}{\tan \left(\frac{\phi_B}{2K} \right)} \cdot \frac{c \cdot \tau}{2 \cdot \sin \left(\frac{\phi_B}{2} \right)}$$

where K is the number of beams 22 covering the receiving sector 18 with the horizontal sector angle
20 ϕ_B .

At the end of the routes 28 traveled by the water craft 10, the memory content of the memory 27 is normalized in block 32. The normalizing is carried out in such a
25 manner that each of the memory values contained in the storage locations of the memory 27 is divided by the sum of the squares of the weighting factors included in the respective memory value. In this context, the weighting factor is the product of receiving
30 sensitivity weighting factor and volume weighting factor in the variant of the method described first, and the receiving sensitivity weighting factor alone in the variant of the method described second. The normalized memory content is deposited in a storage
35 medium 33 (memory 33 in fig. 3) which thus contains the

complete sonar image which can be visually displayed on a display by means of computer graphics technology.

Figure 10 diagrammatically shows an upper route 28 on which the underwater area 10 is "viewed" from aspect angle intervals or sector angles φ_B which point toward another perpendicularly. Each of the routes 28 for the water craft 11, which are above one another, is subdivided into two route sections 281 and 282 which are oriented at right angles to one another. Each route section 281, 282 is dimensioned to be large enough so that each volume element 26 in the analysis space is scanned at least once by the two lateral limiting edges 182, 183 of the receiving sector 18 with the sector angle φ_B from each route section 281, 282. As described with respect to fig. 5, the receiving sector 18 can again be covered by a multiplicity of beams 22 in order to obtain a distance A_y between the measuring points 29 which allows a sufficiently high traveling speed of the water craft 11. The analysis space in the underwater area 10 to be surveyed is scanned once in the x direction along the route section 281 and once in the y direction along the route section 282 and in each case in the z direction with each of the routes 28 traveled which are above one another, so that the analysis space of the underwater area 10 is completely covered at the end of the routes 28. The embodiment of the routes 28 described is of advantage especially if the horizontal sector angle φ_B of the receiving antenna 19 only has small values, e.g. 10° , due to the type of construction. For generating the sonar images of extended underwater areas, a number of routes as shown in fig. 5 and 6 or fig. 10 are cascaded together.

Extending the method described, a beam fan of a number of beams can also be opened perpendicular to the traveling plane, that is to say vertically, their vertical aperture angles φ_v being specified in such a

manner that the sum of the vertical aperture angles φ_v of the beams is equal to the vertical sector angle φ_z of the receiving sector 18. The signal processing per beam 22 remains unchanged as are the back projections of the three-dimensional analysis space. It is only the spherical cuboids which are defined by a beam which is narrow in the vertical direction so that the vertical aperture angle $\varphi_v = \varphi_z$ specified in fig. 6 must be replaced by $\varphi_v = \varphi_z/N$, where N is the number of beams above one another in the vertical direction.

The method described can also be modified to the extent that, instead of a beam fan, only one beam is generated, the horizontal aperture angle φ of which is equal to the horizontal sector angle φ_B . In this case, however, the distance A_y of the measuring points must be very much smaller which is associated with a reduction of the maximum possible traveling speed of the water craft 11. Here, too, however, the horizontal aperture angle φ_B of the receiving sector 18 of the receiving antenna 19 is made as large as is allowed by the installation conditions at the water craft.

In a further variation of the method described, the receiving sector 18 can also be opened on the port side or with two receiving antennas on the starboard and port side of the water craft 11. In the latter case, underwater areas are simultaneously scanned on both sides of the direction of travel. It may also be of advantage if the water craft 11 travels a meander-shaped route. Naturally, it is possible to dispense with the digitization of the output signals of the hydrophones and to perform the method on the basis of analog received signals.

The method described above can also be modified to the extent that, instead of a water craft 11, a diving instrument is used as sonar carrier which travels a

vertical route. In this case, the same method would be performed with a receiving sector rotated by 90° and a beam fan correspondingly rotated by 90° .

Patent claims

1. Method for generating a sonar image of an
5 underwater area (10) by using a sonar carried by a
water craft (11) which has a transmitting antenna (15)
for radiating sound pulses and a receiving antenna (19)
for receiving sound waves back scattered from the
underwater area (10), which spans a receiving sector
10 (18) with a horizontal and vertical sector angle (ϕ_B ,
 ϕ_Z) which is covered by at least one directional
pattern of the receiving antenna (19) having a
predeterminable horizontal and vertical aperture angle
(ϕ , ϕ_v), in which the following method steps are
15 carried out:
- in the underwater area (10), a three-dimensional
analysis space of a multiplicity of volume
elements (26) located adjacently to one another
and above one another is defined,
 - 20 - each volume element (26) is allocated a storage
location in a storage medium (27),
 - the water craft (11) with the receiving sector
(18) pointing to starboard and/or port is moved
over a plurality of straight-line parallel routes
25 (28) which are above one another at a vertical
distance,
 - at successive, preferably equidistant measuring
points (29) along the routes (28), a sound pulse
is emitted in each case and, after being back
30 scattered from the underwater area (10), is
detected as received signal via the directional
pattern and filtered,
 - at each measuring point (29), an amplitude value
is determined from the filter signal produced by
35 the filtering, for each volume element (26) which
is located within the area of the analysis space
bounded by the horizontal and vertical aperture
angle (ϕ , ϕ_v) of the directional pattern, by means
of the position of the volume element (26) in the

analysis space area, in that, in the analysis space area, spherically curved cuboids (30) with a predeterminable radial width, the mean radii of curvature of which are specified by time values taken from the filter signal, multiplied by the velocity of sound, which are adjacent to one another in the radial direction and which extend up to the area boundaries, are formed and the amplitude value, belonging to each time value taken, of the filter signal is assigned to each volume element (26) which is wholly or partially located inside the cuboid (30) determined by the time value,

- the amplitude value determined for each volume element (26) is weighted in dependence on the specific position of the respective volume element (26) in the analysis space area and
- the weighted amplitude values are written into the storage locations allocated to the volume elements (26) and at the same time added to a memory value already present in the storage location.

2. Method according to Claim 1, in which the position-specific weighting of the amplitude values is carried out in such a manner that each amplitude value assigned to a volume element (26) is multiplied by a volume weighting factor which takes into consideration the volume percentage of the volume element (26) located inside the cuboid (30) and/or by a receiving sensitivity weighting factor which takes into consideration the receiving sensitivity of the directional pattern at the location of the volume element (26).

3. Method according to Claim 1 or 2, in which the cuboids (30) are constructed with a radial width corresponding to the desired, preferably maximum resolution and the volume elements (26) are constructed with a square base and cover area which in each case

have edge lengths located in the area of the desired, preferably maximum radial resolution, and with a vertical height (Δ_z).

- 5 4. Method for generating a sonar image of an underwater area (10) by using a sonar carried by a water craft (11) which has a transmitting antenna (15) for radiating sound pulses and a receiving antenna (19) for receiving sound waves back scattered from the
- 10 underwater area (10), which spans a receiving sector (18) with a horizontal and vertical sector angle (ϕ_B , ϕ_z) which is covered by at least one directional pattern of the receiving antenna (19) having a predeterminable horizontal and vertical aperture angle
- 15 (ϕ , ϕ_v), in which the following method steps are carried out:
- in the underwater area (10), a three-dimensional analysis space of a multiplicity of volume elements (26) located adjacently to one another and above one another is defined,
 - 20 - each volume element (26) is allocated a storage location in a storage medium (27),
 - the water craft (11) with the receiving sector (18) pointing to starboard and/or port is moved
 - 25 over a plurality of straight-line parallel routes (28) which are above one another at a vertical distance,
 - at successive, preferably equidistant measuring points (29) along the routes (28), a sound pulse
 - 30 is emitted in each case and, after being back scattered from the underwater area (10), is detected as received signal via the directional pattern and filtered,
 - at each measuring point (29), an amplitude value
 - 35 is determined from the filter signal produced by the filtering, for each volume element (26) which is located within the area of the analysis space bounded by the horizontal and vertical aperture angle (ϕ , ϕ_v) of the directional pattern, by means

of the position of the volume element (26) in the analysis space area, in that for each volume element (26) within the analysis space area, the distance of its center from the centering point of the receiving sector (18) is determined, from this a time value is calculated with the velocity of sound and an amplitude value belonging to the time value is taken from the filter signal with respect to each time value and assigned to the volume element (26),

- the amplitude value determined for each volume element (26) is weighted in dependence on the specific position of the respective volume element (26) in the analysis space area and
- the weighted amplitude values are written into the storage locations allocated to the volume elements (26) and at the same time added to a memory value already present in the storage location.

5. Method according to Claim 4, in which the position-specific weighting of the amplitude values is carried out in such a manner that each amplitude value assigned to a volume element (26) is multiplied by a receiving sensitivity weighting factor which takes into consideration the receiving sensitivity of the directional pattern at the location of the volume element (26).

6. Method according to Claim 4 or 5, in which the volume elements (26) are constructed with a square base and cover area, the edge lengths of which are equal to a desired, preferably maximum or smaller than a desired, preferably maximum radial resolution, and with a vertical height (Δ_z).

7. Method according to Claim 3 or 6, in which the vertical height (Δ_z) is approximately dimensioned as $\frac{c \cdot \tau}{2} \frac{2x_{min}}{z_L - z_I}$ where $z_L - z_I$ is the vertical distance between

the top and the lowest of the routes (28), $x_{\min}$ is the minimum horizontal distance of the analysis space from the routes (28) and $c \cdot \tau / 2$ is the maximum radial resolution with c as the velocity of sound in water and
5 τ as pulse duration of the sound pulses radiated by the transmitting antenna (15).

8. Method according to one of Claims 1 to 7, in which complex group signals obtained by direction-forming are
10 used as received signals.

9. Method according to one of Claims 1 to 7, in which the variation with time of the absolute value or of the quadratic absolute value of complex group signals
15 obtained by direction-forming are used as received signals.

10. Method according to one of Claims 1 to 7, in which the real parts of group signals obtained by direction-
20 forming are used as received signals.

11. Method according to Claim 9, in which the received signal is sampled with a sampling frequency of $1/T$ and the time-discrete received signal is filtered by means
25 of a linear system, the periodic transfer function $H(e^{j\omega T})$ of which is proportional to the amount of the angular frequency ω within the limits defined by half the negative and half the positive angular sampling frequency ($-\pi/2T$ and $+\pi/2T$, respectively) and drops
30 from the bottom limit to zero and rises from zero to the top limit.

12. Method according to one of Claims 1 to 3 and Claim 11, in which discrete time values are sought in the
35 filter signal and the mean curvature radii of the cuboids (30) to be allocated with the time values are calculated by means of the velocity of sound.

13. Method according to one of Claims 4 to 6 and claim 11, in which amplitude values belonging to the time values calculated for the volume elements (26) are obtained by interpolation in the filter signal.

5

14. Method according to one of Claims 1 to 13, in which the memory content of the storage medium (27) is normalized at the end of the routes (28) traveled by the water craft (11).

10

15. Method according to Claim 14, in which the normalizing is carried out in such a manner that each of the memory values contained in the storage locations is divided by the sum of the squares of the weighting factors included in the respective memory value.

15

16. Method according to one of Claims 1 to 15, in which the horizontal sector angle (ϕ_B) of the receiving sector (18) is dimensioned to be as large as possible under installation conditions and the horizontal and vertical aperture angle (ϕ , ϕ_v) of the directional pattern of the receiving antenna (19) is selected to be equal to the horizontal and vertical sector angle (ϕ_B , ϕ_z) of the receiving sector (18).

25

17. Method according to one of Claims 1 to 15, in which a multiplicity of directional patterns placed next to one another horizontally in the manner of a fan with preferably identical horizontal aperture angles (ϕ) and preferably identical vertical aperture angles (ϕ_v) is opened in the receiving sector (18) by means of the receiving antenna (19), which are dimensioned in such a manner that the sum of the horizontal aperture angles (ϕ) is equal to the horizontal sector angle (ϕ_B) of the receiving sector (18) and each vertical aperture angle (ϕ_v) is equal to the vertical sector angle (ϕ_z) of the receiving sector (18).

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18. Method according to one of Claims 1 to 15, in which a multiplicity of directional patterns placed next to one another horizontally and vertically in the manner of a fan, with preferably identical horizontal
5 aperture angles (ϕ) and preferably identical vertical aperture angles (ϕ_v), is opened in the receiving sector (18) by means of the receiving antenna (19), which are dimensioned in such a manner that the sum of the horizontal aperture angles (ϕ) is equal to the
10 horizontal sector angle (ϕ_B) of the receiving sector (18) and the sum of the vertical aperture angles (ϕ_v) is equal to the vertical aperture angle (ϕ_z) of the receiving sector (18).

15 19. Method according to Claim 17 or 18, in which the horizontal sector angle (ϕ_B) of the receiving antenna (19) is dimensioned to be as large as possible under installation conditions.

20 20. Method according to one of Claims 15 to 19, in which each of the parallel routes (28) to be traveled by the water craft (11) is dimensioned to be at least so large that each volume element (26) in the analysis space is scanned at least once by each lateral limiting
25 edge (182) of the receiving sector (18).

21. Method according to one of Claims 1 to 19, in which each of the parallel routes (28) is subdivided into two route sections (281, 282) which are oriented
30 at right angles to one another in the horizontal plane, and each route section (281, 282) is dimensioned to be so large that each volume element (26) in the analysis space is scanned at least once by the front lateral limiting edges (182) in the direction of travel and the
35 rear lateral limiting edge (183) in the direction of travel of the receiving sector (18) from each route section (281, 282).

22. Method according to one of Claims 1 to 21, in
which the center axis (101) of the receiving sector
(18), pointing toward starboard and/or port, is
oriented at an angle of 90° to the longitudinal axis of
5 the water craft (11).