



159159

WO 03/00/1233

PCT/EPO2/05787

METHOD FOR PASSIVE DETERMINATION OF OBJECT DATA

The invention is about a method for passive determination of object data through a selective directional reception from sound waves, which is mentioned as the preamble for a patent in claim 1.

Position, velocity and course of an object (e.g. a surface sea vessel, submarine or torpedo) can be determined without giving away the course of the own carrier vehicle (e.g. surface sea vessel or submarine). Sound waves from the object can be received by a sonar receiver and the bearing angle to the object measured. From this bearing angle, together with the position of the own carrier vehicle, the position of the object and its bearing angle can be estimated and calculated. The difference between the measured and estimated angles will be iteratively made smaller until it reaches a margin of error. This estimated position is recognised as the object position.

Beginning from the position of the object, which for example has been randomly selected as a start position by a selected first bearing beam or else known through other instruments on board, positions from an estimated x-y coordinates for the object is calculated and the bearing angles estimated. The carrier vehicle travels at a constant course during the measurement of the bearing angle for a given time and covers a distance, called its "own distance". The measured bearing angle is compared against the estimated bearing angle and the difference is determined. This difference is minimised until a small remaining error remains between the true and estimated bearing angles. This remaining error is dependent upon a given threshold. Such a filter system is described for example in the DE 34 46 658 C2. The iteration time for this filter system is determined mainly by further inputs. For example, the start position or supporting data is given



G00002

by further observations or measurements from sensors on board the carrier vehicle (e.g. periscopic or radar measurements). Filter coefficients are calculated from these supporting data which leads to a better first estimate of the object position.

The task of this current invention (which is mentioned as the preamble for a patent in claim 1) is the creation of a method which can, without manoeuvring itself and without using other measurement sensor on board a carrier vehicle, determine the object data with certainty and within a tactically appropriate time frame.

This task is to be solved through the characteristics of the method of claim 1.

After an object is detected, the directional reception signals will be grouped into reception signals of an electro-acoustic modifier system, e.g. a horseshoe or side antenna on board a submarine (carrier vehicle) or from an antenna towed by a surface vessel. These signals will undergo a Fourier transformation and the frequency of the spectral lines in the frequency spectrum of group signals will be determined. The frequency of the spectral line with the biggest level recorder or the distance between two neighboring spectral lines (reception frequencies) will be taken together with the measured bearing point as the basis for estimating the object data. Object positions will be estimated and its bearing angles calculated. The difference will be determined between the estimated and measured bearing angles. Also, estimates of a Doppler displacement and a start point beamed sending frequency can be made from the same estimated object position and its change with time. The estimated frequency will, correspondingly with the estimated Doppler displacement, be displaced by the frequency. This creates the estimated Doppler displacement from which the reception frequency can be deducted. The difference between the reception frequency and the estimated Doppler frequency (frequency difference) together with the bearing

point difference will be used for the determination of the object data through the Least-Square-Algorithm.

The advantage of this invention method claim 1 is that the same object data, that is the estimated object positions, is used for the estimate of both the bearing angle and the Doppler displacement. The frequency analysis of the group signals is necessary for determining the reception frequency. This is done normally through a sonar receiver device. This device increases the accuracy of the angle, or the separation of several objects detected in a bearing angle or classification from objects and does not require extra effort for signal processing. The sending frequency of the object as a starting value is determined simply from a measured reception frequency and the assumption of a normal travelling velocity of a sea vessel. This sending frequency is either the frequency of a spectral line (because of the noise from movement of the object), or a signal that is sent out from the object. Including the reception frequency in determining the object data has the advantage that the object data can be determined in a short time without manoeuvring the own carrier vehicle. A further advantage is that two objects that have been travelling for a long time within the same bearing angle can be separated as their reception frequency will be different from one another because of the Doppler displacement. The Doppler displacement shows a remarkable difference in that the radial velocity component between the carrier vehicle and the two objects must be different although the bearing points to both objects do not change.

If the carrier vehicle moves at a constant velocity along a so-called "own distance" at a constant course, the reception frequency changes as it is dependent upon its own radial velocity components and the (pointing in the same direction) radial velocity of the object. With knowledge of our own velocity, we can eliminate our portion of the Doppler displacement and analyze alone the portion belonging to the object. Besides the frequency change over time, the so-called frequency stroke, the bearing point changes over time during the journey over its "own

distance". The time until all object data can be measured with stability is called the convergence time. The convergence time becomes shorter when the frequency stroke becomes bigger by travelling over its "own distance". Measurement tests on a submarine showed that a journey without own manoeuvring and a frequency stroke from a few Hertz can achieve a stable estimate of the course, the distance and the velocity of the object after less than 10 minutes. The velocity of the object in the tests was 10 kn, the velocity of the carrier vehicle was 6 kn, the starting distance between carrier and object was 6 km and the bearing angle at the beginning of the measurements was -45° . If we estimate the object data with only a consideration of the bearing angle, we cannot reach a convergence. An estimation of the object data is possible within a short time only through extra measurement of the reception frequency and the estimation of the Doppler displaced sending frequency

In the advantageous further development of the invention method claim 2, we can utilise the Lofar-Analyse, which is described in L. Kühnle "Classification and Identification – CAI – by Submarine Sonars", Naval Forces Nov. 1987, pg. 27-31. By reception through a tow antenna, an estimation of the object data of very distant objects is reasonable. This is because of the small absorption of deep frequency sound waves in the carrying medium, the good bundling of sound waves and the accuracy of the measurement of the bearing angle, which is large enough because of the small opening angle.

If there is no tow antenna to act as an electro-acoustic modifier system, it is advantageous to undertake the Lofar-Analyse with a side antenna, a so-called Flank array and a Demon-analysis with a horseshoe basis, a so-called Conformal Array. The received noise will undergo a demodulation through a band-pass filtering and the frequency of the spectral lines of the demodularised signals can be determined. These frequencies lie in the same frequency band as

the spectral line (determined through the Lofar-Analyse) and are caused by propeller revs and propeller foliation, as described by the article in the Naval Forces etc.

We get frequencies spectrums with different spectral lines through the Lofar-analysis and the Demon-analysis. The spectral lines with the deepest frequencies distinguish the revs of the propellers. If the frequency is not received, the distance between neighboring spectral lines correspond to this frequency. The frequencies themselves or the distance between frequencies can be utilised as reception frequencies for the determination of the object data.

The accuracy of the frequency analysis and the determination of the reception frequency are tied to the accuracy of the object data estimation. In accordance with the further development of the invention method claim 4, we do not utilise a single frequency, but the frequencies of many spectral lines will be compiled together. Together, they make up the reception frequency. The advantage lies especially in that there is no need to estimate the sending frequency and Doppler displacement of every frequency, but only one single reception frequency goes into the estimation of the object data. The estimation algorithm does not become bigger and despite this, the estimation of the object data is optimised.

The advantage of the further development of the invention method claim 5, 6 and 7 lies in that if a spectral signal falls away, there is no need to calculate a new reception frequency. This is because diverse frequencies on a fictitious spectral frequency of an artificial spectral line can be transformed. These transformed frequency values or their mean measurements can form the reception frequency. If one uses the spectral lines as artificial spectral lines, there is not need to undergo a frequency transformation. On the other hand, the disappearance of the spectral lines by a tracking will not interrupt the estimation. With the transformation of frequency deviations of

frequency values from the fictitious spectral frequencies, the estimate is balanced out through the calculation of the mean.

After the advantageous further development of the invention method claim 8, the frequency deviation is balanced out through a Least-Square-Mean estimation by the displacement of the transformed frequency values to a selected fictitious spectral frequency. Consequently, many spectral lines measurements during the available period are utilised, even when some spectral lines disappear periodically and no valid measurements are taken for them. It is possible to determine the object data through the transformation of the frequencies to a fictitious spectral frequency of an artificial spectral line even if only one spectral line contributes to the fictitious spectral frequency. This signal processing is useable, as all spectral lines of an object have undergone in percentage terms the same Doppler displacement. All irregularities that appear during the tracking by a frequency measurement will be balanced out through the transformation of each spectral line to a same artificial spectral line with a fictitious spectral frequency.

To estimate the Doppler frequency in accordance with advantageous further development of invention method claim 9, a quotient function is determined from the estimated x-y coordinates of the object position. These x-y components, which are subject to error, are determined through a start position of the object and a velocity dependent path term with velocity component errors and path component errors. The start position of the object is formulated for example under consideration of the reach of the sonar reception device in the measured bearing angle. The estimated x-y components are differentiated with time. The sum of the estimated x-y components is formulated as well.

The product of the x-component multiplied with its differentiation with time plus the product of the y-components multiplied with its differentiation with time is divided by the sum of the x-y

components multiplied with the speed of sound to form a quotient function. This function equals the Doppler displacement of an estimated sending frequency that comes from a sound wave beamed from the object. The estimated sending frequency shows a sending frequency error. The estimated Doppler frequency is determined from the difference between the sending frequency (which has a sending frequency error) minus its product with the quotient function. The advantage of the object estimation claim 9 is that the from possible velocity components estimated object position is taken as the basis for the minimisation of the difference in frequency of the reception frequency from the estimated Doppler frequency. The velocity components correspond, with consideration of the bearing to the object, to a radial velocity component which is the cause of the Doppler displacement of the sending frequency of the object. Through the determination and the addition of the reception frequency lies the three decisive advantages- the possibility of determining a first object position and the object data without own manoeuvring, many objects and their data under the same bearing to separate and determine, and to shorten the convergence time for the estimation of the object position.

The path component errors and the velocity component errors as well as the sending frequency errors form an error vector. According to the advantageous further development of the invention method claim 10, the estimated Doppler frequency is calculated with a Taylor series using the error vector. The first member of the vector equals the measured reception frequency and the second member equals the product of the error vector and the frequency coefficient. All other members of a higher order are small enough to be ignored. The frequency coefficient is determined by the partial differentiation of the quotient function after the error vector. A linear estimation model is created through this Taylor development, which gives the frequency deviation between measured reception frequency and the estimated Doppler frequency. This calculation is dependent on the errors of the own position, path and velocity components errors of

the x-y coordinates of the object and also the error of the sending frequency. This linear estimation model can be described with matrices.

According to the advantageous further development of the invention method claim 11, the bearing angle estimation is determined by the x-y components of the object. Beginning from the start position of each x-y component, the path error and the velocity dependent path term is added with the velocity component error. The arctangent of the estimated bearing angle is determined through trigonometrical combination from the estimated x-y components. A linear relationship of the deviation of measured and estimated bearing angles and of the term and velocity component errors is determined by a Taylor expansion of the arctangent function. Partial differentiation of the trigonometrical function after the path error and the velocity component error determines the term coefficients of the series expansion. The series expansion is truncated after the first member and delivers a term coefficient matrix. This term coefficient is determined through an adaptive filter as described for example in DE 34 46 658 C2. Through multiplication with an error vector, which consists of the term and path component errors, one obtains the desired deviation of the measured and the estimated bearing angle.

The advantage of the further development of the invention method claim 11 lies in that the observed error vector is the same as that for the estimation of the Doppler frequency, but that there is no need to take into consideration here the sending frequency failure. The frequency and bearing angle differences that are determined by the Taylor series expansion are summed. The minimum of the sum, which delivers the object data, is iteratively determined.

The advantage of the invention method claim 12 lies in that through a mean calculation of the measured and estimated bearing angle, systematic bearing failures do not enter into the determination of the object data. The systematic bearing errors appear for example, when the

carrier vehicle and object are not found on the same bearing plane, for example the horizontal plane, and the occurring sound waves has an angle, for example an elevation angle. With the sonar reception device, the direction of the sound which corresponds with the projection of the spatial direction of the sound wave on the bearing plane is measured. The systematic bearing error is included in the estimated bearing angle. The mean of the bearing angle and the estimation angle is determined and deducted from the respective measured and estimated bearing angle. The systematic bearing angle under goes the same method of being deducting from every measured and estimated bearing angle. By doing so, the systematic bearing error is not included any more in the calculation of the minimum standard deviation.

The special advantage of invention method claim 12 is that one is indifferent, as to whether the systematic bearing error is caused by an elevation angle or for example, by a compass error or measurement error of the navigation system on board the carrier vehicle. Another advantage is that systematic bearing errors, from sound waves of the object which spreads out over an area because of reflections on the surface level and/or from the bottom of the sea, or because of different water stratification, do not affect the determination of the object data. Unknown slanting positions of the modifier system of the sonar reception device because of water currents do not lead to an erroneous object data although the determination of the own position would be wrong and lead to systematic bearing failures for the determination of the bearing angle. The improved determination of the objection position is guaranteed if systematic bearing failures do not appear. The arctangent function and the mean of the arctangent function are the basis for the determination of the coefficient matrix. Each coefficient consists of term coefficients and its mean. Through multiplication with the error vector, one is able to determine, without any systematic errors, the deviation of the difference of the measured bearing angle minus the mean of the bearing angle as well as the estimated bearing angle minus the mean of the estimated angle.

The systematic error of the bearing angle estimation can be eliminated through the calculation of the mean of the term coefficients and its difference to the actual term coefficients.

The invention is further described in the diagrams with a demonstrative example of a method to the passive determination of object data with sonar reception device. It shows:

Fig. 1 a scenario for the determination of object data

Fig. 2 a x-y coordinate system with object data

Fig. 3 a frequency diagram

Fig. 4 Error plots for determination of object data without manoeuvring

Fig. 5 Error plots for determination of object data with existing systematic errors

Fig. 6 a block schematic

Fig. 7 a chronological progress of a reception frequency measured at sea

Fig. 8 a-d Object data plots based on measurements with a tow antenna

Fig. 9 and 10 Frequencies from measured spectral lines and an artificial spectral line over time

Fig. 11 Object data plot based on measurements of a tow antenna with own manoeuvres

Fig.1 shows a scenario for the passive determination of object data. With an electronic modifier system, e.g. a linear antenna or a tow antenna, a sonar reception device on board a carrier vehicle measures sound from two different objects from the same direction and bearing angle B_1 is measured. One object is on course 1, another on course 2, which are both portrayed in an x-y coordinate system. At time t_0 , the carrier vehicle is at the start 0/0 and the object in a bearing angle in the direction of the y axis, which at the same time takes north as its reference direction. At time t_1 , the carrier vehicle is on course 3 with constant velocity, one object is on course 1 with velocity of v_1 and the other object on course 2 at velocity v_2 travelling to their next target positions. The measured bearing angle B_{1mess} to both object positions is the same and is used for the first estimate of the object data of X_{est} , Y_{est} .

Fig. 2 shows the x-y coordinate system from Fig. 1 at time t . The carrier vehicle with the modifier system is in the position x_e, y_e , which is at the same time the start of the x-y coordinates system. At this time the object is at the position P_{true} . The object is moving away from its start point P_0 at coordinates x_{0true}, y_{0true} with a velocity of V_{xtrue}, V_{ytrue} and put behind it a distance of $V_{xtrue} \cdot \Delta t$ and $V_{ytrue} \cdot \Delta t$. We measure the bearing angle B_{mess} to find the new true position of the object P_{true} . The new position P_{true} of the object will be determined iteratively through the estimated position P_{est} and its bearing angle B_{est} by minimisation of the deviation between B_{mess} and B_{est} .

It is assumed that the object from the coordinate X_{0true} moves with a path failure of Δx_0 to coordinates R_{xest} in x direction with a velocity of v_x , and a velocity component error of Δv_x in a time interval Δt . In the y direction, the object moves during the time interval Δt from the coordinate y_{0true} to coordinates R_{yest} with a path error of Δy_0 and a velocity if v_{yest} and a velocity component error of Δv_y . The coordinates of the objects are estimated with the errors ΔR_x and ΔR_y :

$$R_{x\text{est}} = x_{0\text{true}} + v_x \cdot \Delta t + (\Delta x_0 + \Delta v_x \cdot \Delta t) = R_{x\text{true}} + \Delta R_x \quad (\text{A})$$

$$R_{y\text{est}} = y_{0\text{true}} + v_y \cdot \Delta t + (\Delta y_0 + \Delta v_y \cdot \Delta t) = R_{y\text{true}} + \Delta R_y \quad (\text{B})$$

After reformulation, one gets

$$R_{x\text{true}} = R_{x\text{est}} - \Delta R_x = R_{x\text{est}} - (\Delta x_0 + \Delta v_x \cdot \Delta t) \quad (\text{a})$$

$$R_{y\text{true}} = R_{y\text{est}} - \Delta R_y = R_{y\text{est}} - (\Delta y_0 + \Delta v_y \cdot \Delta t) \quad (\text{b})$$

From this, the estimated bearing angle B_{est} is calculated:

$$B_{\text{est}} = \arctan \frac{R_{x\text{est}} - \Delta R_x}{R_{y\text{est}} - \Delta R_y} \quad \text{I}$$

The true position P_{true} is determined, if the error $\Delta R_x = \Delta x_0 + \Delta v_x \cdot \Delta t$ and $\Delta R_y = \Delta y_0 + \Delta v_y \cdot \Delta t$ equals zero. Then, the velocity components v_x and v_y are correctly estimated, which leads to the acceptance of the new true position of the object P_{true} . This estimated bearing angle B_{est} equals the true bearing angle B_{true} and amounts to:

$$B_{\text{est}} = B_{\text{true}} = \arctan \frac{x_{0\text{true}} + v_{x\text{true}} \cdot \Delta t - x_E}{y_{0\text{true}} + v_{y\text{true}} \cdot \Delta t - y_E} = B_{\text{mess}}$$

The object data $P = (x_0, y_0, v_x, v_y)$ are correctly estimated, when the error vector equals null:

$$\Delta P = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y) = 0 \quad \text{with}$$

$$\Delta p_1 = \Delta x_0, \Delta p_2 = \Delta y_0, \Delta p_3 = \Delta v_x \text{ und } \Delta p_4 = \Delta v_y.$$

The difference between the estimated and measured bearing angle difference is minimised to determine the object data:

$$(B_{\text{est}} - B_{\text{mess}}) = \min$$

The object position P_{true} is to be calculated until a remaining rest error, which is limited by a minimum margin of error. Then is

$$B_{\text{best}} \approx B_{\text{mess}}$$

The inclusion of a estimated Doppler frequency makes it possible to estimate the position without own manoeuvring through a simultaneous minimisation of a frequency difference between measured reception frequency and estimated Doppler frequency under consideration of the bearing angle estimation after equation I.

The object has left the start position P_0 with the velocity $v=v_1$ according to Fig 2. As we know the true angle bearing B_{true} , we can recalculate the velocity component v_x and v_y of the object in a radial velocity component V_R , which is pointing in the direction between the own positions x_e and y_e and P_{true} .

$$V_R = V_R' + V_R'' = v_y \cdot \cos B_{\text{true}} + v_x \sin B_{\text{true}} \quad (C)$$

The radial velocity component V_R takes into consideration the correct algebraic sign of the added radial velocity component of the object V_{RZ} and of the carrier vehicle V_{RE} .

$$V_R = V_{RE} - V_{RZ}$$

Because of the radial velocity component V_R , a sending frequency F_{true} (which is a sending signal or contained in the noise of the object and sent out as a frequency) undergoes a frequency displacement. This reception frequency F_{true} is affected by the Doppler-effect, as described in Chapter 7.4 "The Doppler effect" pg. 334, 335 in the text book "Experimental Physics I", 2nd

Part. Edgar Luescher, University Textbook, Bibliographical Institute, Mannheim 1967. This method applies to that of the Doppler frequency:

$$F_{true} = F_{sttrue} \left(\frac{C + V_{RE}}{C + V_{RE}} \right)$$

One receives through a series expansion after substituting in equation (d) for the reception frequency, an equation which equals the true Doppler affected sending frequency:

$$F_{true} = F_{sttrue} \left[1 - \frac{V_R}{C} \right] \quad (XX)$$

The reception frequency is dependent upon a quotient function, which is proportionate to the radial velocity component V_R :

$$Q = V_R/C \quad (XXI)$$

The radial velocity component V_R is according to equation (c) dependent upon the velocity component in x and y direction v_x and v_y and from bearing angle B_{true} :

$$V_R \approx V_R' + V_R'' = v_y \cdot \cos B_{true} + v_x \sin B_{true} \quad (c)$$

The velocity component v_x and v_y equals the change with time of the x-y coordinates of the object:

$$v_x = \frac{dR_{xtrue}}{dt} = \dot{R}_{xtrue}$$

$$v_y = \frac{dR_{ytrue}}{dt} = \dot{R}_{ytrue}$$

One obtains with the equations (a) and (b):

$$v_x = \dot{R}_{x\text{true}} = \dot{R}_{x\text{est}} - \Delta\dot{R}_x \quad (e)$$

$$v_y = \dot{R}_{y\text{true}} = \dot{R}_{y\text{est}} - \Delta\dot{R}_y \quad (f)$$

With the consideration of the true bearing angle B_{true} between the reference direction N_0 and the direction of the true object position P_{true} ,

$$\sin B_{\text{true}} = \frac{R_{x\text{true}}}{R_{\text{true}}} \quad (g)$$

$$\cos B_{\text{true}} = \frac{R_{y\text{true}}}{R_{\text{true}}} \quad (h)$$

one receives the equations (a) and (b) for the true distance R_{true} to object

$$R_{\text{true}} = \sqrt{R_{x\text{true}}^2 + R_{y\text{true}}^2}$$

$$R_{\text{true}} = \sqrt{(R_{x\text{est}} - \Delta R_x)^2 + (R_{y\text{est}} - \Delta R_y)^2} \quad (i)$$

Also

$$\Delta R_x = \Delta x_0 + \Delta v_x \cdot \Delta t$$

$$\Delta R_y = \Delta y_0 + \Delta v_y \cdot \Delta t.$$

In equation (c), for the radial velocity component V_R , the equations (e), (f), (g), (h) and (i) are substituted in, and one gets for the Doppler displacement the quotient function

$$Q = V_R/c$$

In dependence on the error vector, $\Delta P = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y)$

$$Q(\Delta P) = \frac{1}{C} \frac{(\dot{R}_{x_{est}} - \Delta \dot{R}_x)(R_{x_{est}} - \Delta R_x) + (\dot{R}_{y_{est}} - \Delta \dot{R}_y)(R_{y_{est}} - \Delta R_y)}{\sqrt{(R_{x_{est}} - \Delta R_x)^2 + (R_{y_{est}} - \Delta R_y)^2}} \quad (XXII)$$

The sending frequency F_3 , which is beamed from the object, is estimated with an error ΔF_s .

$$F_{sest} = F_{strue} + \Delta F_s$$

$$F_{strue} = F_{sest} - \Delta F_s$$

and substituted together with the quotient function Q after equation XXII into equation XX for the receiving frequency (which equals the true Doppler frequency F_{true}).

$$F_{true} = (F_{sest} - \Delta F_s) \left[1 - Q(\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y) \right] \quad (XXIII)$$

With an error difference of ΔF , the Doppler frequency F_{true} is estimated as an error

$$F_{true} = F_{est} - \Delta F$$

and substituted in equation XXIII. For each bearing angle measurement i , the Doppler frequency must be determined from the estimated position

$$F_{sest} - \Delta F_i = G_i(\Delta P) = (F_{sest} - \Delta F_s) \left[1 - Q(\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y) \right] \quad (XXIV)$$

The error vector ΔP is to be estimated including the error term ΔF_s for the estimation of the sending frequency F_{sest} .

$$\Delta P_1 = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y, \Delta F_s) \quad (XXV)$$

The error vector ΔP will be used to estimate the Doppler frequency the equation XXIV in a Taylor series and is truncated after the second element.

$$G_i(\Delta P) = G_i(\Delta P) \Big|_{\Delta P=0} + \sum_{l=1}^5 \left[\frac{\partial G_i}{\partial \Delta P_l} \Big|_{\Delta P=0} \right] \cdot \Delta P_l \quad (XXVI)$$

The estimated Doppler frequency F_{iest} equals the measured reception frequency F_{imess} for $\Delta P=0$:

$$G_i(\Delta P) \Big|_{\Delta P=0} = F_{iest} \Big|_{\Delta P=0} = F_{imess} \quad (XXVII)$$

Equation XXVII is substituted into equation XXVI and one gets for the estimated Doppler frequency:

$$F_{iest} = G_i(\Delta P) = F_{imess} + \sum_{l=1}^5 \left[\frac{\partial G_i}{\partial \Delta P_l} \Big|_{\Delta P=0} \right] \cdot \Delta P_l$$

a sum, which equals the measured reception frequency F_{imess} plus the frequency difference ΔF_1

$$G_i(\Delta P) = F_{imess} + \Delta F_1 = F_{iest}$$

$$\Delta F_1 = F_{imess} - F_{iest}.$$

For determining the Doppler frequency, one must minimise the frequency difference ΔF_1 :

$$\Delta F_1 = \sum_{l=1}^5 \left[\frac{\partial G_i}{\partial \Delta P_l} \Big|_{\Delta P=0} \right] \cdot \Delta P_l \quad (XXVIII)$$

$$\Delta F_1 = \sum_{l=1}^5 g_{il} \cdot \Delta P_l = F_{imess} - F_{iest} \quad (IXXX)$$

Through partial differentiation of the estimation equation XXIV, where the quotient function $Q(\Delta P)$ after equation XXII is substituted in, after the error vector ΔP_1 according to the equation XXV, one gets the frequency coefficient (g_{i1}) in the following relation:

$$g_{i1} = \frac{F_{sest}}{C \cdot R_{iest}} \left[\dot{R}_{xiest} - \frac{R_{xiest} \cdot (R_{xiest} \cdot \dot{R}_{xiest} + R_{yiest} \cdot \dot{R}_{yiest})}{x \cdot R_{iest}^2} \right] \quad XXXI$$

$$g_{i2} = \frac{F_{sest}}{C \cdot R_{iest}} \left[\dot{R}_{yiest} - \frac{R_{yiest} \cdot (R_{xiest} \cdot \dot{R}_{xiest} + R_{yiest} \cdot \dot{R}_{yiest})}{x \cdot R_{iest}^2} \right] \quad XXXII$$

$$g_{i3} = \frac{F_{sest}}{C \cdot R_{iest}} R_{xiest} + g_{i1} \cdot \Delta t_1 \quad XXXIII$$

$$g_{i4} = \frac{F_{sest}}{C \cdot R_{iest}} R_{yiest} + g_{i2} \cdot \Delta t_1 \quad XXXIV$$

$$g_{i5} = \frac{R_{xiest} \cdot \dot{R}_{xiest} + R_{yiest} \cdot \dot{R}_{yiest}}{C \cdot R_{iest}} - 1 \quad XXXV$$

Many frequency coefficients g_{i1} are multiplied with the corresponding error of error vector ΔP_1 after equation IXXX. The frequency difference is iteratively minimised through estimation of the x-y component of the position of the target together with the bearing angle difference according to equation I.

The estimated bearing angle after equation I

$$B_{iest} = \arctan \frac{R_{x_{iest}} - \Delta R_{x_i}}{R_{y_{iest}} - \Delta R_{y_i}} \quad \text{IV}$$

is developed in a Taylor series around the error vector $\Delta P_1 = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y)$. This may not contain the frequency error ΔF_s , but is otherwise equal to the error vector given in equation XXV, and is truncated after the second element:

$$B_{iest}(\Delta P) = B_{iest} \Big|_{\Delta P=0} + \sum_{i=1}^4 \frac{\partial B_{iest}}{\partial \Delta P_i} \Big|_{\Delta P=0} \cdot \Delta P_i$$

With

$$\frac{\partial B_{iest}}{\partial \Delta P_i} \Big|_{\Delta P=0} = h_{i1}$$

as term coefficient, one gets:

$$B_{iest}(\Delta P) - B_{iest} \Big|_{\Delta P=0} = \sum_{i=1}^4 h_{i1} \cdot \Delta P_i, \quad \text{V}$$

Here, the estimated bearing angle B_{iest} equals the measured bearing angle B_{mess} , when the error vector ΔP equals null.

$$B_{iest} \Big|_{\Delta P=0} = B_{mess} \quad \text{VI}$$

The term coefficient h_{i1} in equation V is determined through partial differentiation of the estimated bearing angle B_{iest} according to equation IV after the path error and velocity component error of the error vector $\Delta P = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y)$:

$$h_{i1} = \left. \frac{\partial B_{iest}}{\partial \Delta x_0} \right|_{\Delta P=0} = \frac{\partial}{\partial x_0} \left[\arctan \frac{R_{xiest} - \Delta R_{xi}}{R_{yiest} - \Delta R_{yi}} \right]$$

$$h_{i1} = \frac{-R_{yiest}}{(R_{xiest})^2 + (R_{yiest})^2} \quad (1)$$

The differentiation after $\Delta P_2 = \Delta y_0$ gives the term coefficient:

$$h_{i2} = \left. \frac{\partial B_{iest}}{\partial \Delta y_0} \right|_{\Delta P=0} = \frac{R_{xiest}}{(R_{xiest})^2 + (R_{yiest})^2} \quad (2)$$

One gets the coefficient h_{i3} and h_{i4} through partial differentiation of the velocity component errors $\Delta v_x = \Delta P_3$, $\Delta v_y = \Delta P_4$ and substituting into (1) and (2)

$$h_{i3} = \left. \frac{\partial B_{iest}}{\partial \Delta v_x} \right|_{\Delta P=0} = \Delta t_i \cdot h_{i1} \quad (3)$$

$$h_{i4} = \left. \frac{\partial B_{iest}}{\partial \Delta v_y} \right|_{\Delta P=0} = \Delta t_i \cdot h_{i2} \quad (4)$$

The term coefficient h_{i3} and h_{i4} equals the product of the time interval Δt_i and the term coefficients determined earlier, h_{i1} and h_{i2} .

Through substituting (1), (2), (3) and (4) in equation 5, one gets the bearing angle difference D and its square δ :

$$\delta = \left[B_{iest} - B_{imes} \right]^2 = \sum_{i=1}^4 \left[h_{i1} \cdot \Delta P_i \right]^2 \quad VII$$

The estimation equation for the object data is formed from equation VII and IXXX.

With each measurement and estimate i of the bearing angle B_{mess} , B_{iest} and measurement of the reception frequency F_{mess} and estimation of the Doppler frequency F_{iest} , the minimum is iteratively determined over $1k$ measurements and estimates:

$$\sum_{i=1}^{1k} (B_{mess} - B_{iest})^2 + (F_{mess} - F_{iest})^2 = \min$$

$$\sum_{i=1}^{1k} \left[\sum_{j=1}^4 [h_{i,j} \cdot \Delta P_j]^2 + \sum_{j=1}^5 [g_{i,j} \cdot \Delta P_j]^2 \right] = \min \quad \text{XXX}$$

The calculated object data (based on the minimum) gives the position, velocity and course of the object with the object data vector $P = (x, y, v_x, v_y, F)$

Fig 3 shows a frequency diagram with the reception frequency F_{z1} , F_{z2} , F_{z3} and F_{z4} over the time t from 4 objects. These objects all beam the same frequency $F_s = 1000$ Hz. Each reception frequency F_{z1} , F_{z2} , F_{z3} , F_{z4} consists of an object term and an own term because of the relative radial velocity component V_R from the carrier vehicle and the object. The frequency stroke during the start and duration of the object is, with a constant velocity of the object, dependent upon the measured bearing angle B_{mess} . Where the reception frequencies F_{ze1} , F_{ze2} , F_{ze3} and F_{ze4} equals the sending frequency $F_s = 1000$ Hz, the radial velocity component would equal null and the place of the next approximation CPA reached. For the first object Z_1 , the Doppler displacement of the sending frequency F_s and hence the frequency stroke of the reception frequency F_{z1} from 3 Hz and the passing time from the CPA of 7 minutes is the shortest. For the fourth object, the Doppler displacement and the frequency stroke of the reception frequency F_{z4} is the largest, as the fourth object comes close to a collision course with the receiving modifier system. The frequency stroke corresponds to a quotient function Q according to the relative, radial velocity components V_R between object and carrier vehicle in equation XXI and XXII.

The estimation equation XXX takes in each time interval Δt as its basis the measured bearing angle B_{mess} and the reception frequency F_{mess} . From this, the bearing, distance, velocity and course of the object as object data are iteratively determined.

Fig 4 gives error plots for the determination of the object data, where at the beginning of the journey, the object's distance to the its objective is 20 km, the bearing to objective is $B_0=0^\circ$ opposite the north direction N_0 , the velocity 11.3 m/s = 22 kts, the course of the object is 155° , the course of the own carrier vehicle is 25° and its velocity is 6 kts.

Fig. 4a shows, that the bearing failure during the entire journey lies within an error width of $\pm 0.5^\circ$. The relative distance error over time $\Delta R / \%$ is given in Fig 4b. The estimation of the distance R converges after 15 minutes and shows by 20 Monte-Carlo runs after 20 minutes, a deviation from less than $\pm 10 \%$ without manoeuvres. The velocity error is shown in Fig. 4c, it lies at 17.5 minutes by an object velocity of 11.3 m/s in an error width of ± 1 m/s. The course is already stable after 10 minutes and lies in a error width of $\pm 10^\circ$ as shown in Fig 4d.

A false measurement of the bearing angle B_{mess} because of a systematic bearing error ϑ is eliminated through inclusion of the average of the measured and estimated bearing angle during the passage of the carrier vehicle at constant course and velocity along a so-called "own distance". This systematic bearing error ϑ appears for example, when the direction N_0 for example, through an erroneous determination of the own position because of the modifier system, is not exactly pointing in the north direction N_0 (shown in Fig. 2). The systematic bearing error ϑ can appear because of errors in the compass display, through sound in a slanted angle at the bearing plane or through use of a tow antenna through water currents or currents influenced by the

propeller of the carrier vehicle. The bearing angle B_{mess} is measured against the erroneous North direction No' and is bigger by the bearing error ϑ .

To eliminate the systematic bearing value ϑ , a bearing angle mean is calculated over $1k$ measurements of B_{mess} , which is measured at time intervals Δt_i .

$$\overline{B_{mess}}^k = \frac{1}{1_k} \sum_{i=1}^{1_k} B_{mess}$$

And the mean of the estimated bearing angle B_{iest} after equation I can be calculated:

$$\overline{B_{iest}}^k = \frac{1}{1_k} \sum_{i=1}^{1_k} \arctan \frac{R_{xiest} - \Delta R_{xi}}{R_{yiest} - \Delta R_{yi}} = \overline{\arctan \frac{R_{xest} - \Delta R_x}{R_{yest} - \Delta R_y}}^k$$

II

The estimated difference values are formed from the difference of the actual estimated bearing angle B_{iest} after equation I and the mean of the estimated angle $\overline{B_{iest}}^k$ after equation II for each "own distance" k :

$$F_1^k = B_{iest} - \overline{B_{iest}}^k \quad \text{III}$$

$$F_1^k = \arctan \frac{R_{xiest} - \Delta R_{xi}}{R_{yiest} - \Delta R_{yi}} - \overline{\arctan \frac{R_{xest} - \Delta R_x}{R_{yest} - \Delta R_y}}^k \quad \text{IV}$$

The estimated difference value F_1^k is developed in a Taylor series with the error vector $\Delta P = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y)$ and truncated after the second element:

$$F_1^k = B_{1\text{est}} - \overline{B_{\text{est}}}^k \quad \text{III}$$

$$F_1^k = \arctan \frac{R_{x1\text{est}} - \Delta R_{x1}}{R_{y1\text{est}} - \Delta R_{y1}} - \overline{\arctan \frac{R_{x\text{est}} - \Delta R_x}{R_{y\text{est}} - \Delta R_y}}^k \quad \text{IV}$$

With

$$\left. \frac{\partial F_1^k}{\partial \Delta P_1} \right|_{\Delta P=0} = \gamma_{11}^k$$

as coefficient, one gets

$$F_1^k(\Delta P) - F_1^k|_{\Delta P=0} = \sum_{i=1}^4 \gamma_{i1}^k \cdot \Delta P_i,$$

where,

$$F_1^k|_{\Delta P=0} = B_{1\text{mess}} - \overline{B_{\text{mess}}}^k$$

shows the difference in the measurement values from the actual measured bearing angle $B_{1\text{mess}}$ and the mean of the bearing angle on a "own distance" k measured bearing angle $\overline{B_{\text{mess}}}^k$. The coefficient γ_{i1}^k in equation V are determined through partial differentiation of the estimated difference values F_i according to IV after the path error and the velocity component error of the error vector $\Delta P = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y)$. The coefficient γ_{i1}^k is set out of term coefficients h_{i1}^k and its mean $\overline{h_{i1}}^k$ together. The term coefficient h_{i1} is differentiated from the equations (1), (2), (3), (4). The coefficients are:

$$\gamma_{i1}^k = h_{i1}^k - \overline{h_1^k} \quad (5)$$

$$\gamma_{i2}^k = h_{i2}^k - \overline{h_2^k} \quad (6)$$

$$\gamma_{i3}^k = \Delta t_1 \left[h_{i1}^k - \overline{h_1^k} \right] \quad (7)$$

$$\gamma_{i4}^k = \Delta t_1 \left[h_{i2}^k - \overline{h_2^k} \right] \quad (8)$$

Through substitution of the coefficient γ_{i1} in equation V, one gets as bearing angle difference the difference from the estimated difference value F_i^k according to III and the measured difference value $F_i^k|_{\Delta F=0}$ according to VI:

$$\begin{aligned} D_1 &= \left\{ \left[B_{i\text{est}} - \overline{B_{\text{est}}^k} \right] - \left[B_{i\text{meas}} - \overline{B_{\text{meas}}^k} \right] \right\}^2 = \\ &= \sum_{i=1}^4 \left\{ \left[h_{i1}^k - \overline{h_1^k} \right] \cdot \Delta P_1 \right\}^2 \end{aligned} \quad \text{VIII}$$

The measuring angle difference after equation VIII and the frequency difference after equation IX form the basis for determining the object data and are iteratively eliminated over 1k measurements and estimates:

$$\begin{aligned} &\sum_{i=1}^k \left\{ \left[B_{i\text{meas}} - \overline{B_{\text{meas}}^k} \right] - \left[B_{i\text{est}} - \overline{B_{\text{est}}^k} \right] \right\}^2 + \left[F_{i\text{meas}} - F_{i\text{est}} \right]^2 \Big\} = \\ &= \sum_{i=1}^k \sum_{l=1}^4 \left\{ \left[h_{il}^k - \overline{h_l^k} \right] \cdot \Delta P_l \right\}^2 + \sum_{l=1}^5 \left[g_{il} \cdot \Delta P_l \right]^2 \Big\} = \min \end{aligned} \quad \text{IX}$$

Fig. 5 shows error plots by an estimate of the object data after equation VIII, where the carrier vehicle must have been manoeuvred as there are no frequency measurements and estimates used for analysis of the object data.

Fig. 5a shows over time t the systematic error failure θ . It amounts to roughly 1.2° during the journey over its “own distance”. The first manoeuvre of M1 is characterised by the bearing error of -1.2° increasing to $+1.2^\circ$ after the end of the manoeuvre and travel of the second “own distance”. By the next manoeuvre M2 after 8 minutes, the bearing error jumps to -1.2° and remains unchanged during the measurement along the next “own distance”. The manoeuvres M1, M2, ... M5 are each shown and numbered by vertical lines on top of the error plots.

The distance errors $\Delta R / \%$ in Fig 5b, velocity error ΔV m/s in Fig. 5c and the course error K in Fig 5d are after 15 minutes and three manoeuvres within a normal error width.

Fig. 6 shows a block schematic of a sonar receiving device for the determination of the target data P with an adaptive filter system to evaluate bearing angle B_{imess} and reception frequency F_{imass} . Reception signals of a modifier system 10 are detected in a direction processor 11 through runtime compensation or phase compensation and bundled into group signals and the object is detected under the bearing angle B_{imess} with a measure arrangement 12. The measure detection 12 is steered from a control circuit 13 in intervals of Δt . The entire signal processing runs in intervals of Δt_1 . The measurement circuit 12 is junior to an estimation circuit 15, which uses as entry data: the north from a compass arrangement 16 N_0 as reference direction, the own position x_e, y_e of the modifier system 10 from a navigations device 17 on board, starting position $P_0 = (x_0, y_0)$ of the object from starting circuit 18, velocity component v_{ix} and v_{iy} in x - y direction as well as an error vector of $\Delta P = (\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y, \Delta F_s)$ from an estimation system 20. From these

entry data, the estimation circuit 15 is estimated according to the estimation equation (A) and (B) path component R_{xiest} , R_{yiest} , and path error ΔR_{xi} , ΔR_{yi} . From these estimation values, a bearing angle B_{iest} is calculated after equation I through an arctangent circuit.

In a bearing angle difference circuit 23, which is junior to the estimation circuit 15, the estimated path component R_{xiest} , R_{yiest} and its error ΔR_x , ΔR_y and their dependent term coefficients h_{i1} after equation (1), (2), (3), (4) as well as its mean value $\overline{h_1}$ formed. From this, the coefficient γ_{i1}^k is calculated after equation (5), (6), (7), (8) and summarised as measurement angle differences after the estimation equation VII and VIII:

$$\delta_i^* = \left[B_{imeas} - B_{iest} \right]^2 = \sum_{l=1}^4 \left\{ h_{il} \cdot \Delta P_l \right\}^2 \quad \text{VII}$$

$$\delta_i = \sum_{k=1}^{1k} \left\{ \left[B_{imeas} - \overline{B_{imeas}}^k \right] - \left[B_{iest} - \overline{B_{iest}}^k \right] \right\}^2 = \sum_{k=1}^{1k} \sum_{l=1}^4 \left\{ \left[h_{il}^k - \overline{h_{il}}^k \right] \cdot \Delta P_l \right\}^2 = \min \quad \text{VIII}$$

Over $i=1k$ measurement of each “own distance”, whose number $1k$ is already given in a steering circuit 60, the measured and estimated bearing angle B_{imeas} and B_{iest} are evaluated. The time period $1k \cdot \Delta t$ gives the filter length.

The group signals at the beginning of the direction processor 11 are analysed in a frequency analysis circuit 24. The calculated reception frequency is added to a frequency difference circuit 25, which is junior to the estimation circuit 25. The frequency difference ΔF_i after estimation

equation IXXX is determined from the estimated path components R_{xiest} , R_{yiest} and its changes with time $\dot{R}_{xiest}$ and $\dot{R}_{yiest}$ as well as the errors ΔR_{xi} , ΔR_{yi} and $\Delta \dot{R}_{xi}$ and $\Delta \dot{R}_{yi}$:

$$\Delta F_i \cong \sum_{l=1}^5 g_{il} \cdot \Delta P_l \cong F_{imesb} - F_{iest} \quad (IXXX)$$

The outputs of the bearing angle differentiation circuit 23 and the frequency differentiation circuit 25 are linked to the iterations circuit 30. Here, the minimum of the sum of the bearing angles difference and frequency difference or its squared difference values is determined according to the estimation equations:

$$\sum_{i=1}^{l_k} \left[\sum_{l=1}^4 [h_{il} \cdot \Delta P_l]^2 + \sum_{l=1}^5 [g_{il} \cdot \Delta P_l]^2 \right] = \min \quad (XXX)$$

and

$$\begin{aligned} & \sum_{i=1}^{l_k} \left\{ \left[B_{imesb} - \overline{B_{mess}}^k \right] - \left[B_{iest} - \overline{B_{est}}^k \right] \right\}^2 + \left[F_{imesb} - F_{iest} \right]^2 \Bigg\} = \\ & = \sum_{i=1}^{l_k} \sum_{l=1}^4 \left\{ \left[h_{il}^k - \overline{h_l}^k \right] \cdot \Delta P_l \right\}^2 + \sum_{l=1}^5 \left[g_{il} \cdot \Delta P_l \right]^2 \Bigg\} = \min \end{aligned}$$

(XL)

The minimisation is run for so long, until the error vector ΔP_l reaches a lower border ΔP_l which is lower than the limit ΔP_{min} .

In the estimation circuit 15, path components R_{xest} , R_{yest} as well as path errors ΔR_x and ΔR_y for each bearing angle B_{imesb} are calculated for so long until the error vector ΔP_l reaches a lower border $\Delta P_l \leq \Delta P_{min}$. Except for a determined rest error limit, the estimated bearing angle B_{est} equals the true bearing angle B_{true} and the estimated path and velocity components R_{xest} , R_{yest} ,

v_{xest} , v_{yest} equal the true path and velocity components R_{ytrue} , R_{xtrue} , V_{xtrue} , V_{ytrue} and the estimated Doppler frequency F_{iest} equals the true Doppler frequency F_{true} . The limit circuit 31 is shifted on after the iteration circuit 30 and controls the estimation arrangement 20. By going below the limit ΔP_{min} , the object data P would be shown in a display 100.

Fig 7 shows the reception frequency of F_{z1} (from the object beamed spectral line with a sending frequency of $F_s = 1000$ Hz) over a time progression, when the carrier vehicle with the modifier system is doing a manoeuvre. For the measurement of the manoeuvre M1, the tow antenna is important, which is started at a time $t=15$ minutes after the object has at the time $t=7.5$ reached the area of the largest approximation CPA, where the reception frequency F_{z1} equals the sending frequency F_s . At the beginning of the measurement, the reception frequency $F_{z1} = 1003.8$ Hz and after 15 minutes it equals 996.3 Hz. At this time point, the tow antenna is turning because of the manoeuvres M1 and the reception frequency F_{z1} begins to rise to 998 Hz. At the end of the manoeuvres, the reception frequency F_{z1} goes down again over a time t .

The invention method, with addition of the time progression of the reception frequency F_{z1} after the determined object data in Fig. 7, can be gathered from the diagram in Fig. 8. In the scenario as shown in Fig. 7, a manoeuvre is done after 15 minutes. Fig. 8a shows that the course of the object, which lies between 28° and 34° , can be estimated with stability already after 3 minutes. Fig. 8b shows that the invention method estimated distance of R to the object converges after less than 2.5 minutes. One sees, that the distance R comes down within the first minute and reaches the CPA after 7.5 minutes. After that the distance R to the object becomes bigger. Fig. 8c shows the progress with time of the estimated sending frequency $F_s \approx 1000$ Hz. After 15.5 minutes, the curve is interrupted because at this time point, the own manoeuvre M1 of the tow antenna is started. During this course manoeuvre M1, no measurement data is evaluated. The velocity

v/m/s of the object (which moves between 4.8 and 5.1 m/s) can be estimated with certainty after already 3 minutes as can be seen from Fig. 8d.

For the calculation of the object data in Fig. 8, a filter length of 30 minutes is used. This means that measured bearing angles B_{imess} and reception frequencies F_{imess} that are older than 30 minutes are not used. But the object data plots in Fig. 8 shows that one can in less than 5 minutes estimate the object data with certainty through using frequency information. One can hence work with a filter length or time limit of for e.g. 5 minutes. This has the advantage that by manoeuvres of the object, the object data can be estimated with certainty after 5 minutes again without operating intervention.

The group signals are analysed together with the sounds received by the system modifier 10 in the frequency analysis circuit 24. A Lofar-gram is created by using the linear side antenna or a tow antenna as system modifier 10, where the deepest frequency spectral lines of the received noise is recognised and its frequency F_i is ascertained. In the same manner, the use of a side antenna, a so-called Flank array, undertakes a Demon analysis of the directional characteristics of the signals at the start of the direction processor 11. The received sound is demodularised through a band pass filtering. The modularised frequency is analysed and shows the same frequencies spectral lines like the Lofar-gram. The spectrum with the ground frequency and its harmony is caused by the revs of the sea vessel's moving propellers.

The spectral analysis delivers for example two spectral lines at the beginning of the scenario, the measured frequency $F_1 = 1045$ Hz and $F_2 = 1005$ Hz. Their progression with time is shown in Fig. 9. Both measured frequencies F_1 and F_2 , which belongs to the unknown beamed sending frequencies $F_{s1} = 1000$ Hz and $F_{s2} = 1040$ Hz, comes from the same object and are percentage-wise affected with the same Doppler displacement. They are compiled together into an artificial

spectral line and then analysed with the object data analysis. The fictitious spectral frequency of the artificial spectral line is for e.g. fixed at $F_{kunst} = 1030$ Hz. For determining the reception frequency F_{mess} , many frequencies F_{1i} , which are measured in time interval Δt , are captured, compiled and validated. These validated frequencies F_{g1} is used for the transformation of the measured frequency F_{1i} , where the fictitious spectral frequencies F_{kunst} is divided by the valid frequency F_{g1} and then multiplied with the momentarily measured frequency F_{1i} . One gets the frequency values on the artificial spectral lines transformed F_{k1} , as measurement values of the reception frequency F_{mess} , which moves in a very tight border around the fictitious spectral frequency $F_{kunst} = 1030$ Hz.

$$F_{k1} = F_{mess} = \frac{F_{kunst}}{F_{g1}} \cdot F_{1i}$$

The second measured Frequency F_2 amounts to 1005 Hz and is recalculated by the same fictitious spectral frequency $F_{kunst} = 1030$ Hz, where the fictitious spectral frequencies $F_{kunst} = 1030$ Hz is divided by the validly measured frequency F_{g2} and then multiplied with the momentarily measured frequency F_{2i} :

$$F_{k2} = F_{mess} = \frac{F_{kunst}}{F_{g2}} \cdot F_{2i}$$

Fig. 9 shows besides the measured frequency F_{1i} and F_{2i} , the frequency F_{k1} and F_{k2} over the time interval t , which shows an offset of circa 2.7 Hz to one another. The transformed frequency F_{k2} is displaced or reversed at its mean deviation in direction of the transformed frequency F_{k1} . The results are shown in Fig. 10. The progress of the spectral line F_k is supplied as the reception frequency F_{mess} for the analysis of the object data.

Results of the object data analysis under consideration of the spectral frequency F_k as reception frequency F_{mess} is shown in the diagram in Fig. 11. Fig 11a shows the bearing angle B over the time t/min . The distance estimates to the object are already stable into the first manoeuvre M1 after 8 minutes as shown in Fig. 11b. The distance R between the carrier vehicle with the modifier system and the object amounts to 7 km after 5 minutes. Fig. 11c shows the velocity $v/\text{m/s}$ of the object over the time t , which also assumes stable values of between 3 m/s to 5m/s after 3 minutes.

Only the course is not yet clearly determinable during this time as shown in Fig. 11d. But also before the first manoeuvre M1 is started, the course is estimated with certainty after 7 minutes. After 8 minutes, the carrier vehicle manoeuvres at a velocity of M2. It can be gathered from many object data plots 1a-11c, that this velocity manoeuvre M2 does not disturb the object data estimation, but confirms the current values. The manoeuvre M2 ends after 4 minutes. This velocity manoeuvre M2 leads, because of a change in the radial velocity V_R , to a change in the Doppler displacement and with that the reception frequency F_{mess} . This change is not noticeable negatively during the analysis of the object data. The second velocity manoeuvre M2 after 19 minutes also does not lead to a lost in the object data determination. After 29 minutes, the carrier vehicle travels a course manoeuvre, where the bearing angle from vessel to object changes and this change is very large. During this time, a stable estimation of the bearing angle is not possible, as can be gathered from the gaps in the curve in Fig. 11 a. After the manoeuvre M3 ends, the stable estimation of the bearing angle is again possible after 32.5 minutes. This course manoeuvre M3 does not however disturb the course determination k of the object (Fig. 11d), nor the distance estimation (Fig. 11b), and nor the velocity determination (Fig. 11c).

In summary it can be determined, as shown clearly from the object data plots in Fig. 11, that the first object data estimates without manoeuvres reaches a convergence time in less than 7 minutes

and that the velocity and course manoeuvres of the carrier vehicle does not prolong this convergence time.

PATENT CLAIMS

1. Method to passive determination of object data, through a directional selective reception of sound waves beamed or sent from an object, with an electronic acoustic modifier system of a sonar reception device on a carrier vessel of estimated bearing angle, which is determined from estimated positions of the object, and measured bearing angles, there the bearing angle differences between measured and estimated bearing angle are iteratively minimised, this is characterised that from the bearing angle received sound waves is put through a frequency analysis and the frequency is determined at least as a reception frequency (F_{iness}) of a spectral line, that a frequency difference (ΔF_i) of the reception frequency (F_{iness}) is calculated from an estimated Doppler frequency (F_{iest}), that the estimated Doppler frequencies (F_{iest}) from an estimated beamed sending frequency from the object (F_{sest}) and a Doppler displacement (Q) from estimated object positions (R_{xiest} , R_{yiest}) are used to calculate the estimated bearing angle (B_{iness}), and whose changes with time ($\dot{R}_{xiest}$, $\dot{R}_{yiest}$) in the bearing angle is determined and that the minimum of the sum of the bearing angle difference (δ_i , δ_i^*) and frequency difference (ΔF_i) or its squared difference can be iteratively determined,

$$\sum_{i=1}^n \left[\left(B_{iness} - B_{iest} \right)^2 + \left(F_{iness} - F_{iest} \right)^2 \right] = \min$$

where the object data is found by reaching the minimum of the estimated positions.

2. Method according to claim 1, characterised by the determination of the reception frequency with a Lofar-analysis.

3. Method according to claim 1, characterised by the determination of the reception frequency with a Demon-analysis.
4. Method according to each claim 1-3, characterised by that measured frequencies of many spectral lines are compiled together and form measurements of the reception frequency F_{mess} .
5. Method according to claim 4, characterised by that the measured frequencies of several spectral lines individually of frequency values of a fictitious spectral frequency of a common artificial spectral line is transformed and makes up the measurements of the reception frequency F_{mess} .
6. Method according to claim 5, characterised by that the fictitious spectral frequency is the measured frequency of one of the received spectral lines.
7. Method according to claim 5, characterised by that the means of the transformed frequency values forms measurements of the reception frequency F_{mess} .
8. Method according to claim 5 or 6, characterised by that a mean squared deviation of all transformed frequency values is calculated from a selected transformed frequency value and the transformed frequency values are displaced by this deviation and makes up measurements of the reception frequency F_{mess} .
9. Method according to claims 1-8, characterised by the x-y components ($R_{x\text{iest}} - \Delta R_x$; $R_{y\text{iest}} - \Delta R_y$) from a starting position (x_0, y_0) including a velocity dependent path term

$[(v_x + \Delta v_x) \cdot \Delta t, (v_y + \Delta v_y) \cdot \Delta t]$ with velocity component errors ($\Delta v_x, \Delta v_y$) and path component error ($\Delta x_0, \Delta y_0$), which are multiplied with its differentiation with time and the subsequent product is divided by the sum of the x-y components and forms the quotient function,

$$Q(\Delta P) = \frac{1}{c} \frac{(\dot{R}_{x_{est}} - \Delta \dot{R}_x)(R_{x_{est}} - \Delta R_x) + (\dot{R}_{y_{est}} - \Delta \dot{R}_y)(R_{y_{est}} - \Delta R_y)}{\sqrt{(R_{x_{est}} - \Delta R_x)^2 + (R_{y_{est}} - \Delta R_y)^2}}$$

which is equal to the Doppler displacement, that the estimated sending frequency (F_{sest}) which is reduced by a sending frequency error (ΔF_s) with the difference from one and the quotient function are multiplied together and that the at the frequency difference (ΔF_i) erroneously estimated Doppler displacement gives

$$F_{iest} - \Delta F_i = (F_{sest} - \Delta F_s) \left[1 - Q(\Delta x_0, \Delta y_0, \Delta v_x, \Delta v_y) \right] \quad (XXIII)$$

10. Method according to claim 9, characterised by that the error vector (ΔP) which is formed from the path component error ($\Delta x_0, \Delta y_0$), the velocity component error ($\Delta v_x, \Delta v_y$) and the sending frequency error (ΔF_s), that the estimated Doppler frequency ($F_{iest} - \Delta F_i$) is determined in a Taylor series at the error vector (ΔP), as its frequency coefficient is determined through partial differentiation after the error vector (ΔP), its first element equals the measured reception frequency (F_{iness}) and its second element is equal to the product from frequency coefficient (g_{it}) multiplied with the error vector (ΔP) and the frequency difference (ΔF_i) to determine the minimum :

$$\Delta F_1 = \sum_{i=1}^5 g_{i1} \cdot \Delta P_1$$

11. Method according to claims 1-10, characterised by that the trigonometrical function from the x-y components ($R_{xiest} - \Delta R_{xi}$; $R_{yiest} - \Delta R_{yi}$) is calculated, that the bearing angle difference is calculated through a Taylor series expansion of the trigonometric function, that an error vector (ΔP_1) from the path component error ($\Delta x_0, \Delta y_0$) and the velocity component error ($\Delta v_x, \Delta v_y$) makes up the variables of the Talyor series expansion, that its term coefficients (h_{i1}) through partial differentiation of the trigonometrical function after the error vector (ΔP_1) is determined, its first element equals the measured bearing angle (B_{imess}) and its second element equals the product of the term coefficient (h_{i1}) multiplied with the error vector ΔP_1 , and the bearing angle difference forms,

$$\delta_i^* = \left[B_{imess} - B_{iest} \right]^2 = \sum_{i=1}^4 \left\{ h_{i1} \cdot \Delta P_1 \right\}^2$$

that the sum of the squared bearing angle differences and its squared frequency difference is iteratively minimised and its minimum gives us the object data.

$$\sum_{i=1}^{1k} \left[\left(B_{imess} - B_{iest} \right)^2 + \left(F_{imess} - F_{iest} \right)^2 \right] = \sum_{i=1}^{1k} \left\{ \left[\sum_{i=1}^4 h_{i1} \cdot \Delta P_1 \right]^2 + \left[\sum_{i=1}^5 g_{i1} \cdot \Delta P_1 \right]^2 \right\} = \min$$

12. Method according to claims 1-11, characterised by that over a time period during a straight movement of the carrier vehicle along an “own distance”, a number (1k) of bearing angles (B_{imess}) to the object are measured and a bearing angle mean ($\overline{B_{mess}}$) from

the measured bearing angle (B_{mess}) is determined, and to each measured bearing angle (B_{mess}) an estimated bearing angle (B_{iest}) is calculated, that a estimated angle mean ($\overline{B_{iest}}$) from the estimated bearing angle (B_{iest}) is calculated, that) the bearing angle mean ($\overline{B_{mess}}$) is deducted from each measured bearing angle (B_{mess}) and the estimated angle mean ($\overline{B_{iest}}$) is deducted from each estimated bearing angle (B_{iest}) and a measurement difference value and estimation difference value is formulated, that the measurement difference value and the estimation difference value is subtracted, and this subtraction gives the estimated bearing angle (B_{iest}) from the measured bearing angles (B_{mess}) from systematic bearing angle ϑ of a free bearing angle deviation (D) and that during the time interval ($1k \cdot \Delta t_i$), the sum of the bearing angle deviations (D) and the frequency difference (ΔF_i) or the squared deviation of the bearing angle and squared frequency difference is calculated and that the minimum of the sum is iteratively calculated and gives the object data:

$$\sum_{i=1}^k \left\{ \left[\left(B_{mess} - \overline{B_{mess}} \right) - \left(B_{iest} - \overline{B_{iest}} \right) \right]^2 + \left(F_{mess} - F_{iest} \right)^2 \right\} = \min$$

13. Method according to claims 11 and 12, characterised by the trigonometrical function and the formation of its mean value, that the deviation or standard deviation is determined through a Taylor series expansion of the trigonometrical function and its mean value after the error vector (ΔP_1), its coefficient (γ_{i1}) equals the term coefficient (h_{i1}) and its mean values ($\overline{h_1}$), that its first element equals the measurement differences and its second element equals the product of the coefficient (γ_{i1}) multiplied with the error vector (ΔP_1)

and forms the deviation (D), that the sum of the squared deviation and squared frequency difference is minimised:

$$\sum_{i=1}^k \left\{ \left[\sum_{j=1}^4 (h_{ij} - \bar{h}_i) \cdot \Delta P_j \right]^2 + \left[\sum_{j=1}^5 g_{ij} \cdot \Delta P_j \right]^2 \right\} = \min$$

Certified True Translation

Translated by Low Wee Him



Asia - Link Translation Services
13 Anson Road #30-18
International Plaza, Singapore 079903
Tel: 223 3972 Fax: 223 5508