

PROCEDURE FOR ELIMINATING GHOST SOURCES FROM PASSIVE SONAR COMPRISING SEVERAL LINEAR ANTENNAS.

FIELD OF THE INVENTION

This invention concerns the field of passive sonar systems simultaneously operating several linear antennas for coast, harbor or port
5 zone surveillance. This invention mainly concerns harbor surveillance systems comprising several passive linear antennas installed on the seabed and located around the roadstead.

This invention relates to the data processing field. More precisely, the problem handled concerns the elimination of ghost sources that appear when
10 processing angles measured from a linear antenna.

CONTEXT OF THE INVENTION – PRIOR ART

Standard linear antennas, also called "streamers", generally comprise
15 a set of omni-directional unit acoustic sensors or hydrophones located along the antenna. This structure makes angular measurements ambiguous with such antennas. The direction of the incoming acoustic signal corresponding to a bearing in relation to a given antenna, of the object, which emitted the signal, is not directly accessible as the field of ambiguity is defined around
20 the axis of the antenna by a cone of revolution. The conical angles measured in this manner are still called "pseudo-bearings". When the source is far, or even at a shallow depth, the incoming elevation of the acoustic waves is close to zero. Then there is, from the angle at which the source is detected, two possible values symmetrical in relation to the reference axis,
25 being the antenna axis (right/left ambiguity) which are converted into two azimuth values θ and θ' also called Az^+ and Az^- . The azimuth conventionally represents here the value of the angle defined by the north and the signal incoming direction, which corresponds to the "source-to-antenna" axis. These two azimuth values define two separate directions in space, of which
30 only one corresponds to the effective position of the source.

A known method to eliminate the right/left ambiguity in the case of linear antennas consists of splitting the antenna using two or more parallel

linear antennas and by combining the signals received by each antenna to make up a reception channel, for which the diagram is not ambiguous.

Another known method is to equip the streamer with directive acoustic
5 sensors or groups of omni-directional elementary sensors, for example, hydrophone triplets, devices enabling some right/left rejection.

In the case of a surveillance network comprising linear antennas laid on the sea bed, the use of hydrophone triplet linear antennas is not
10 necessarily an appropriate solution to efficiently eliminate the ambiguity, as the phases of the signals received may be disturbed by reflections on the sedimentary layers. Consequently, the right/left rejection obtained may be of a lower quality than in deep water. The same applies when two streamers are used in parallel. In this case, there is either an additional supplementary
15 problem in ensuring the parallelism if the streamers are not precisely side-by-side or the disadvantage of a possible loss of sensitivity if they are.

These two known methods have, in all cases, the disadvantage of increasing the number of hydrophones required to make up a linear antenna.
20 The effect of this increase is to increase the manufacturing cost of the linear antenna implemented and this of the associated receiver, and therefore the global cost of the system required for complete coverage of a zone.

Another method is to operate coherently the two antennas
25 simultaneously, i.e. make up a channel formation encompassing all sensors of the two antennas. In a less costly manner, partial coherent processing may be made by, for example, time correlation of signals from the source and from the two antennas. The disadvantage of these up-line signal-processing techniques is that the sensors must be sampled in a perfectly synchronous
30 manner. This assumes that it is possible to distribute a common clock signal to the two antennas, which is not always possible. Furthermore, this assumes that access to signals transiting in the up-line processing system of the sonar is available, which is not always possible if already existing sonars are used.

In the case of a towed antenna, therefore mobile, it is in addition possible to eliminate the right/left ambiguity by varying the orientation of the antenna. However, to do this the ship must maneuver in a manner so that the operation eliminating the ambiguity takes a relatively long time (typically
5 around 10 minutes). Furthermore, this possibility is not available when working with fixed antennas.

The current methods making it possible to eliminate the ambiguity with fixed antennas, therefore appear as being costly solutions requiring in addition the implementation of more powerful means of computation to
10 handle the increase of information flow following the implementation of a greater number of sensors. The use of more complex antennas associated with more powerful processing means entail a significant increase to the global cost of the surveillance sonar system. Therefore, the preference is to use conventional antennas fitted with omni-directional sensors, which are
15 ambiguous.

One of the consequences from the ambiguity of angle measurement is that when there is a need to locate the source by triangulation, there may be several intersections in the lines of sight. Only one corresponds to the
20 effective source, the others being false solutions, called ghost sources that are to be eliminated even though the antennas constituting the network remain right/left ambiguous.

PRESENTATION OF THE INVENTION

25

One purpose of the invention is to propose a solution making it possible to use omni-directional sensor passive linear antennas, naturally ambiguous, to make up an underwater surveillance system capable of eliminating ghost sources appearing during the detection of sources located
30 in the monitored zone or starting to enter this zone.

To this end, the object of the invention is a procedure for eliminating the ambiguity in the localization of a signal source and the rejection of "ghost" sources due to this ambiguity by means of a passive sonar comprising at

least two linear antennas, A and B, separate one from the other. The procedure according to the invention mainly comprises:

- An initial step (step 21) involving the acquisition of azimuth measurement $\theta(t_i)$ and measurements of the frequency $f(t_i)$ of the signal received. The measurements are made at different moments of measurement t_i . The signal received corresponds, to within the Doppler effect, to the signal emitted by the source(s) detected(s).

10 A second step (step 22) for determination of the speed values corresponding to the different potential sources, and possibly the corresponding frequency f_0 of the signal emitted by these sources. This estimation of the parameters characterizing the potential sources is made using the frequency values measured $f(t_i)$ and azimuth values $\theta(t_i)$ measured
15 during the first step (step 21) at different moments t_i ,

A third step (step 23) consists of determining the real source and eliminating the wrong solutions (ghost sources). During this step, the coherence of the values associated with each potential source are assessed
20 in relation to a model represented by a set of measurement equations linking incoming direction and the received signal frequency to the speed, position and possibly to the transmission frequency of the potential source involved. Then the ambiguity is eliminated by determining the potential source for which the speed, position and frequency values, satisfy these equations for
25 each measurement moment t_i . This potential source is considered as the real source. The other potential sources, considered as ghost sources, are rejected.

According to an initial method of implementation of the invention for
30 two antennas A and B,, the measurement equations used during step 23, are equations linking the Doppler frequency of the signal received to the frequency f_0 , to the azimuth θ and to the Cartesian components v_x and v_y of speed V of the source.

According to an initial variant of this first implementation mode of the procedure, according to the invention, during step 22, the components v_x and v_y of the potential source speed involved, whether real or ghost, will be determined by triangulation (intersection of the lines of sight from two
5 antennas) at different moments.

According to a second variant of this first implementation mode, the possible values of the frequency f_0 and components v_x and v_y of the speed of the object involved are calculated during step 22, by performing a series of N
10 frequency measurements $f(t_i)$ and azimuth measurements $\theta(t_i)$ received by each of the antennas at consecutive moments t_i . These three unknowns are computed by solving an over-determined linear system by the least square method.

To this end, the azimuth measurements $\theta_A(t_i)$ and $\theta_B(t_i)$ obtained by means of
15 antennas A and B are used, and the linear equation system represented by the $2N$ relations expressed in a synthetic manner by the following equation is solved:

$$F = M \cdot X$$

20

where X represents the status vector $X = [f_0; f_0 v_x; f_0 v_y]^T$ and where M represents a measurement matrix with $2N$ lines, in which each line is expressed as follows (c , celerity of sound assumed known):

$$25 \quad M_A(t_i) = [1; -\sin\theta_A(t_i)/c; -\cos\theta_A(t_i)/c]$$

or

$$M_B(t_i) = [1; -\sin\theta_B(t_i)/c; -\cos\theta_B(t_i)/c],$$

each line $M_A(t_i)$ or $M_B(t_i)$ corresponding to a measurement moment t_i , and F to
30 a vector with $2N$ components constituted by the measurement pairs of frequencies received ($f_A(t_i)$, $f_B(t_i)$) measured at N moments t_i .

6

According to these two variants, the measurement equations used during step 23 are expressed as follows:

$$f_{A_i}(t_i) = f_0 [1 - (v_x \cdot \sin \theta_{A_i}(t_i) + v_y \cdot \cos \theta_{A_i}(t_i)) / c]$$

5

$$f_{B_i}(t_i) = f_0 [1 - (v_x \cdot \sin \theta_{B_i}(t_i) + v_y \cdot \cos \theta_{B_i}(t_i)) / c]$$

where c represents the celerity of sound, assumed known, and where v_x and v_y represent the components of speed $\vec{v}$ of the source in a Cartesian reference system.

According to a third variant of this first implementation mode, the components v_x and v_y of the potential source speed considered are determined, during step 22, by applying an extended Kalman filter on the status vector $X = [x; v_x; y; v_y; f_0]$ subject to a certain status noise defined beforehand to estimate the possible values of the Cartesian components of the speed of the object emitting the measured signal and of the corresponding frequency of the emitted signal.

According to this variant, the remainder or the innovations issued from the filter are analyzed during step 23. Subsequently, the real source then corresponds to the residuals mostly centered around zero.

According to a second mode of implementation of the invention, for two antennas A and B, the measurement equations used during step 23 are equations linking the Doppler frequency of the signal received to the frequency and to the radial speed $\dot{\rho}$ of the source. At reference moment t_R (any reference moment) they are expressed as follows:

$$f_{A_R}(t_R) = f_0 [1 - \dot{\rho}_A(t_R) / c]$$

30

$$f_{B_R}(t_R) = f_0 [1 - \dot{\rho}_B(t_R) / c]$$

the values $\dot{\rho}_A(t_R)$ and $\dot{\rho}_B(t_R)$ are determined separately from the measurements collected at each antenna by solving the equation system:

$$\sin\theta_A(t_R) \cdot \dot{\rho}_A(t_R) - \sin\theta_B(t_R) \cdot \dot{\rho}_B(t_R) = -\cos\theta_A(t_R) \cdot \rho_A(t_R) \cdot \dot{\theta}_A(t_R) + \cos\theta_B(t_R) \cdot \rho_B(t_R) \cdot \dot{\theta}_B(t_R)$$

$$\cos\theta_A(t_R) \cdot \dot{\rho}_A(t_R) - \cos\theta_B(t_R) \cdot \dot{\rho}_B(t_R) = \sin\theta_A(t_R) \cdot \rho_A(t_R) \cdot \dot{\theta}_A(t_R) - \sin\theta_B(t_R) \cdot \rho_B(t_R) \cdot \dot{\theta}_B(t_R)$$

5

where $\dot{\theta}_A(t_R)$ and $\dot{\theta}_B(t_R)$ represent the derivative values of the azimuth measurements $\theta_A(t_R)$ and $\theta_B(t_R)$ at this same reference moment t_R .

According to a first variant of this second implementation mode, the derivatives $\dot{\theta}_A(t_R)$ and $\dot{\theta}_B(t_R)$ are determined by linear Kalman filtering of angle measurement made during step 21 (status vector Kalman filter (θ , $\dot{\theta}$), or alpha-beta filtering)

According to another variant of this second implementation mode, $\dot{\theta}_A(t_R)$ and $\dot{\theta}_B(t_R)$ are determined by a graphic method.

Whatever the method of implementation of the invention, the procedure according to the invention makes it possible to advantageously eliminate the ghost sources by means of a sonar system using conventional passive linear antennas, which present inherently a right/left ambiguity, and this without additional equipment being necessary.

The procedure according to the invention is advantageously adaptable to a large range of sonar systems that may comprise a variable number of linear antennas distant one from the other.

Advantageously, the procedure according to the invention is implemented using conventional measurements of frequency and bearing. The elimination of ambiguity to the measured bearing by different antennas is obtained by using the results from measurements made on signal samples obtained at different measurement moments.

DESCRIPTION OF THE FIGURES

The characteristics and the advantages of the different aspects of the invention will clearly appear in the following description. The description is
5 associated with the attached figures representing

- figure 1, an illustration of the ambiguity problem appearing when linear antennas comprising omni-directional acoustic sensors are used,
- figure 2, an organizational chart of the mains steps of the procedure
10 according to the invention,
- figure 3, illustration of the first implementation mode of the procedure according to the invention,
- figure 4, illustration of the situation corresponding to the detection of an object according to a uniform rectilinear movement (MRU).
- 15 - figures 5 and 6, illustration of a second implementation mode of the procedure according to the invention,

DETAILED DESCRIPTION

20 First of all, consider figure 1, illustrating the specific case of a passive sonar system comprising three linear antennas A, B and C of which the axes are illustrated by segments 11, 12, and 13. With this type of system, an object 14 emitting a signal with sinusoidal components in an omni-directional manner may be detected by each of the antennas. When the signal source is far or
25 when detection is made in a shallow zone, the incoming elevation of the acoustic waves may, in general, be considered as being close to zero. Subsequently the system has at its disposal, for each antenna, two angles of measurement corresponding to symmetrical directions, 15-18, 16-19 or 17-111, in relation to the antenna axis. These angle measurements are each
30 converted into two azimuth values called θ^+ and θ^- related to the detected object. For example, an azimuth θ^+ , corresponds to the real position of the source of the signal received and an azimuth θ^- , for example, corresponds to a virtual position of the source. In this case a ghost source is invoked. It is assumed here that there is only one real source. In the case of multiple
35 sources, it is assumed that it is possible to associate beforehand the tracks

from each source, for example, by testing the similarity of the frequencies received or their time fluctuations.

This ambiguity, which appears at each antenna considered separately from the others is naturally eliminated when the system involved comprises at least three antennas detecting the source. In fact, as illustrated by the figure, the real position of the object, which emitted the detected signal, may be determined simply by triangulation. Only axes 15, 16 and 17, corresponding to the directions in which the object is effectively located in relation to each of the antennas, incorporate an intersection corresponding approximately to the real position of the object, whereas axes 18, 19 and 111, corresponding to the virtual directions, do not incorporate any common intersection.

On the other hand, as we see in figure 1, if the system only comprises two antennas or if detection is only made by two of the antennas comprising the system, the ambiguity of the position cannot be eliminated in such a simple manner.

Then consider figure 2 showing the organizational chart of the steps of the procedure according to the invention.

As can be seen in this figure, the procedure according to the invention comprises three main steps:

- an initial step, 21, for acquisition of data normally provided by a passive sonar. This data is azimuth measurements $\theta(t_i)$ and frequency measurements $f(t_i)$ of the signal received,
- a second step, 22, for estimation of the parameters representing the kinematics of each potential source and possibly its transmission frequency.
- a third step, 23, for assessment for each potential source, of the coherence of the estimated values and measured magnitudes; a step performing the selection operation of the real source and elimination of ghost sources.

The first step of the procedure according to the invention, step 21, consists of analyzing the signals received by the two linear antennas A and B, by applying a conventional narrow band passive sonar processing operation on these signals. The spectrum of the signal received may be a pure frequency or even a narrow band line spectrum.

Thus, for each antenna, the frequencies (f_A and f_B) of the signal received as well as bearings G_A and G_B are determined, in which the detected object is located in relation to each of the antennas. As stated previously, this bearing is determined with a right/left ambiguity. Therefore the two possible bearing values for each antenna are obtained; bearing values, which are translated by two azimuth values θ_A^+ (θ_B^+) and θ_A^- (θ_B^-) for each antenna. As stated previously, the azimuth represents here, in a conventional manner, the value of the angle defined by the north direction and the direction linking the center of symmetry of the antenna to the signal source, as these angles are counted down positively clockwise. Thus, for each antenna two azimuth values θ^+ and θ^- are obtained, of which only one corresponds to the real direction in which the detected source is located. According to the invention, the frequency and bearing measurements are made at different moments t_i .

The second step of the procedure according to the invention, step 22, consists of determining the movement speed of the source by means of its Cartesian components v_x and v_y for example, in a fixed reference. This determination is by means of azimuth values measured in the previous step 21, knowing that the source is considered as being in an approximately uniform rectilinear motion (MRU) during the measurement time. As said previously, this azimuth measurement is an ambiguous measurement, giving two possible azimuth values for each antenna. Thus, , step 22 naturally provides several possible values of the source speed; values of which one truly corresponds to the source and of which the others can be called ghost sources.

As shown in this figure, the implementation of the procedure according to the invention assumes that the surveillance system involved comprises at least two linear antennas of which the axes are not co-linear, i.e. not aligned on the same straight line. This restriction represents the general case of the surveillance systems considered, in view of the laying constraints of antennas in a roadstead. Nevertheless, for other cases of use, it is necessary to take this restriction into account when the positioning of the antennas making up the system is defined.. Figure 3 illustrates the case of a

system comprising two linear antennas A and B, case using a typical but non-limitative example.

Note that there are numerous cases where the intersection of the lines of sight corresponding to the segments, materializing the incoming direction of the signal on each antenna, do not always exist for the two possible directions of each antenna. The case illustrated by figure 3 corresponds to a case where the orientation of the antennas entails an ambiguity, a case where it is necessary to eliminate the ambiguity. In a different case, for example, the case of a sonar system of which the antennas layout is relatively similar to the layout of antennas 12 and 13 of figure 1 the ambiguity in determining the position of the detected source does not exist, two of the sighting directions having no point of intersection. In addition, in certain other cases, one of the two determined positions is located in an impossible location, for example on a nearby coast. In such a case, the determination of the solution corresponding to the real source during step 23 is simple and immediate.

The third step of the procedure according to the invention, step 23 consists, as previously explained, of eliminating the ambiguity resulting from steps 21 and 22. During this step, the real source is determined and the ghost sources eliminated. To achieve this, the speed composition and possibly the frequency values are considered for each potential source and then these values are verified to check whether they satisfy, for each moment t_i , the measurement equations linking the incoming directions and the frequency of the signals received to the speed, the position of the source and possibly the frequency of the signal emitted by the potential source involved. The potential source satisfying these measurement equations is accepted. The other sources are rejected, as being ghost sources.

Depending on the implementation method selected and the reference selected to express the potential source position and speed measurements, the measurement equations are expressed differently. In the rest of the descriptions, several implementation methods are presented as examples.

Now, figure 3 is considered, which illustrates a first implementation method of the procedure according to the invention.

- As this figure illustrates, in this first implementation method presented as an example, the procedure according to the invention performs, in step 22, the estimation of the parameters associated with the movement of the object at the source of the detected signal, especially its movement speed or, more exactly in this case, the components of this speed defined in an absolute Cartesian reference of which one of the axes, axis y in the example in the figure, is plotted by the north direction..
- 10 The incoming directions determined are materialized on the figure by half-straight lines 31 to 38. The intersection of the half-straight lines (or lines of sight) corresponding to a given moment, make it possible to define the potential positions that may correspond to the position of the object at a given moment. Amongst these potential positions, only one corresponds to the real position of the object and the others correspond to virtual objects or ghost sources.

- Thus, for example, the intersections of segments 31 and 32 on the one hand and segments 33 and 34 on the other hand make it possible to estimate the two possible positions M_2 and M'_2 for the source at moment t_2 , positions identified by their Cartesian coordinates x and y. Then using the estimated positions at moments t_1 and t_2 , it is possible to determine the two corresponding speeds v and v'.

- Note here that, because amongst the two positions M_i and M'_i estimated at a given moment t_i , one is real and the other virtual, the same applies to the estimated speeds $\vec{V}$ and $\vec{V}'$ and therefore determining which of the speeds is virtual, is the same as determining what is the true incoming direction of the signal.

- In a first variant of this first implementation method, the Cartesian components v_x and v_y of the speed vector are estimated by triangulation, according to a method called indirect or semi-graphic. As illustrated in figure 3, this method consists in practice in determining, for example, graphically, the positions $M(x, y)$ and $M'(x', y')$ of the source corresponding to the azimuths measured at moments t_i . This, for example, may be done using

graphic tools. Then the corresponding speed vectors $\vec{V}$ and $\vec{V}'$ are determined using the determined positions.

Thus in the example of the figure 3, the possible positions of the source are determined by means of measurements made at two consecutive moments, t_1 and t_2 , on the signals received by antennas A and B. Thus for M_1 and M'_1 on the one hand for $t = t_1$ and M_2 and M'_2 on the other hand for $t = t_2$ are obtained.

Using these positions, the possible corresponding values $\vec{V}$ and $\vec{V}'$ of the speed vector are estimated. Movement of the source is assumed uniform and rectilinear. In practice, the Cartesian components (v_x, v_y) and (v'_x, v'_y) of vectors $\vec{V}$ and $\vec{V}'$ are determined by means of the following relation:

$$v_x = \frac{x_2 - x_1}{t_2 - t_1} \text{ and } v'_x = \frac{x'_2 - x'_1}{t_2 - t_1} \quad [1]$$

$$v_y = \frac{y_2 - y_1}{t_2 - t_1} \text{ and } v'_y = \frac{y'_2 - y'_1}{t_2 - t_1} \quad [2]$$

In a second variant of this first implementation mode, the Cartesian components v_x and v_y of the speed vector estimated by means of a method called the direct method, consisting of defining a transposed vector X^T of the status vector $X = [f_0; f_0 v_x; f_0 v_y]$, and a measurement matrix M where each line is defined for a measurement moment t_i given by one of the following relations:

$$M_A(t_i) = [1; -\sin\theta_A(t_i)/c; -\cos\theta_A(t_i)/c] \quad [3]$$

25 and

$$M_B(t_i) = [1; -\sin\theta_B(t_i)/c; -\cos\theta_B(t_i)/c] \quad [4]$$

where $\theta_A(t_i)$ corresponds for the moment t_i considered, to one of the possible incoming directions of the signal on antenna A, whereas $\theta_B(t_i)$ corresponds to one of the possible incoming directions of the signal on antenna B; c representing here, as previously stated, the celerity of sound.

In such a manner, a vector F , of dimension $2N$, of which the components correspond to N pairs of frequency measurements ($f_A(t_i)$, $f_B(t_i)$) of the signals received by antennas A and B , obtained for N consecutive moments t_i , may be defined by the following relation:

5

$$F = M \cdot X \quad [5]$$

where M is the measurement matrix consisting of $2N$ lines $M_A(t_i)$ and $M_B(t_i)$.

10 The expression of the components of vector F is then:

$$F_A(t_i) = M_A(t_i) \cdot X \quad [6]$$

and

$$F_B(t_i) = M_B(t_i) \cdot X \quad [7]$$

15

Subsequently, the estimation of X will then be made by resolution of this over determined linear system, as per the least square method.

In this first implementation mode of the procedure according to the
20 invention, especially for the two variants described previously, the expression of the equation of measurements considered is:

$$f_A(t_i) = f_0 [1 - (v_x \cdot \sin \theta_A(t_i) + v_y \cdot \cos \theta_A(t_i)) / c] \quad [8]$$

25

$$f_B(t_i) = f_0 [1 - (v_x \cdot \sin \theta_B(t_i) + v_y \cdot \cos \theta_B(t_i)) / c] \quad [9]$$

where c represents the celerity of sound, assumed known, and where v_x and v_y represent the components of the speed $\vec{v}$ of the source in a Cartesian reference system.

30

Subsequently, step 23 of the evaluation of the coherence consists, first of all, of calculating for each moment t_i considered, the value of magnitude v^m defined by the relation:

35

$$v^m(t_i) = (f_A(t_i) - f_B(t_i)) / (f_A(t_i) + f_B(t_i)) \quad [10]$$

where $f_A(t_i)$ and $f_B(t_i)$ represent the frequency measurements of the signal received by each of the antennas at measurement moment t_i .

- According to this method, the pair of estimated values (v_x, v_y) or (v'_x, v'_y) of the Cartesian components of the speed of the object is considered and for each antenna the computation is made for each pair of magnitude v defined by the relation:

$$v(t_i) = \frac{v_x \cdot (\sin \theta_A(t_i) - \sin \theta_B(t_i)) + v_y \cdot (\cos \theta_A(t_i) - \cos \theta_B(t_i))}{v_x \cdot (\sin \theta_A(t_i) + \sin \theta_B(t_i)) + v_y \cdot (\cos \theta_A(t_i) + \cos \theta_B(t_i)) - 2c} \quad [11]$$

10

where $\theta_A(t_i)$ and $\theta_B(t_i)$ represent the azimuths measured at the moment t_i considered.

- Thus, for each potential source, a given value of magnitude v is obtained. Thus, for a system comprising two antennas A and B and for each measurement moment t_i , there are four possible values of the magnitude v , being values corresponding to the association of the different measured azimuth values:

$$v_1(t_i) = \frac{v_x (\sin \theta_A(t_i) - \sin \theta_B(t_i)) + v_y (\cos \theta_A(t_i) - \cos \theta_B(t_i))}{v_x (\sin \theta_A(t_i) + \sin \theta_B(t_i)) + v_y (\cos \theta_A(t_i) + \cos \theta_B(t_i)) - 2c} \quad [12]$$

$$v_2(t_i) = \frac{v_x (\sin \theta_A(t_i) - \sin \theta'_B(t_i)) + v_y (\cos \theta_A(t_i) - \cos \theta'_B(t_i))}{v_x (\sin \theta_A(t_i) + \sin \theta'_B(t_i)) + v_y (\cos \theta_A(t_i) + \cos \theta'_B(t_i)) - 2c} \quad [13]$$

$$v_3(t_i) = \frac{v_x (\sin \theta'_A(t_i) - \sin \theta_B(t_i)) + v_y (\cos \theta'_A(t_i) - \cos \theta_B(t_i))}{v_x (\sin \theta'_A(t_i) + \sin \theta_B(t_i)) + v_y (\cos \theta'_A(t_i) + \cos \theta_B(t_i)) - 2c} \quad [14]$$

25

$$v_4(t_i) = \frac{v_x (\sin \theta'_A(t_i) - \sin \theta'_B(t_i)) + v_y (\cos \theta'_A(t_i) - \cos \theta'_B(t_i))}{v_x (\sin \theta'_A(t_i) + \sin \theta'_B(t_i)) + v_y (\cos \theta'_A(t_i) + \cos \theta'_B(t_i)) - 2c} \quad [15]$$

Subsequently, the evaluation operation of the coherence itself consists of then calculating for each value v , the deviation value $v - v^m$. The value of v

given the lowest deviation $v-v^m$ then corresponds to the position of the potential source representing the real source. The other potential sources are then considered as ghost sources and are then rejected.

5 In a third variant of this first implementation mode, step 21 consists of, in an even more direct manner, applying an extended Kalman filter "EKF" to the status value $X = [x; v_x; y; v_y; f_0]$ subject to a certain previously defined status noise.

10 The measurement equations used during steps 23 are then as follows, where the symbol "Atan" represents the Arctangent function:

$$\theta_A = \text{Atan} \frac{x_A}{y_A} \quad [16]$$

and

$$15 \quad \theta_B = \text{Atan} \frac{x_B}{y_B} \quad [17]$$

for the azimuth measurements,

$$f_A(t_i) = f_0 [1 - (v_x \cdot \sin \theta_A(t_i) + v_y \cdot \cos \theta_A(t_i))/c] \quad [18]$$

20 and

$$f_B(t_i) = f_0 [1 - (v_x \cdot \sin \theta_B(t_i) + v_y \cdot \cos \theta_B(t_i))/c] \quad [19]$$

for the frequency measurements.

25 The quantities f_A , f_B , θ_A and θ_B represent the values of the signal frequency received and the azimuth measured during step 21, for each of the two antennas A and B.

30 In this variant, a possible method to assess the coherence of measurements with regard to the model consists, when possible, of estimating the transmission frequency f_0 of the source and, on the conditions that there are a sufficient number of measurements, in testing the frequency remainders made up by the different deviations between calculated

frequencies $[f_A(t_i), f_B(t_i)]$ using estimated values of the speed and azimuth values at moments t_i and the values $[f_A^m(t_i), f_B^m(t_i)]$ measured on the signal samples received at different moments t_i .

Subsequently, the real position of the source is then where the greatest
5 amount of remainders centered around zero is obtained.

Then consider figures 5 and 6 illustrating a second implementation mode of the procedure according to the invention. In this second mode, attention is paid to the parameters characterizing the movement of the
10 source detected directly in relation to the antenna involved, especially the distance ρ separating the source of the antenna involved and the radial speed $\dot{\rho}$ of the source in relation to this same antenna.

According to this second implementation mode, measurement step 21
15 consists, as previously and for each of the antennas A and B, of measuring the frequency f_A or f_B of the signal received (with the offset due to the Doppler), and on the other hand, of measuring the azimuths θ_A or θ_B corresponding to the incoming direction of the signal emitted by the source. According to this implementation mode, these measurements are made
20 consecutively at different moments t_i .

According to this second implementation mode, step 22 consists of determining the radial speed $\dot{\rho}$ of the source, measured by each antenna, at reference moment t_R . According to the invention, this speed $\dot{\rho}(t_R)$ is
25 calculated from the corresponding radial distance $\rho(t_R)$ and the drift of the azimuth measurement $\theta(t_i)$ noted $\dot{\theta}(t_R)$. Thus, for two antennas A and B, $\rho_A(t_R)$, $\rho_B(t_R)$, $\dot{\theta}_A(t_R)$, $\dot{\theta}_B(t_R)$ is determined and subsequently $\dot{\rho}_A(t_R)$ and $\dot{\rho}_B(t_R)$.

According to the invention, the radial distances are calculated from
30 azimuth measurements using the following relations:

$$\begin{aligned} x(t_R) - x_A &= \rho_A(t_R) \cdot \sin \theta_A(t_R) \\ y(t_R) - y_A &= \rho_A(t_R) \cdot \cos \theta_A(t_R) \end{aligned} \quad \text{for antenna A} \quad [20]$$

and

$$\begin{aligned} x(t_R) - x_B &= \rho_B(t_R) \cdot \sin \theta_B(t_R) \\ y(t_R) - y_B &= \rho_B(t_R) \cdot \cos \theta_B(t_R) \end{aligned} \quad \text{for antenna B} \quad [21]$$

where (x_A, y_A) and (x_B, y_B) respectively represent the assumed known
 5 coordinates of antenna A and antenna B relatively to a Cartesian reference
 system of which the y axis coincides with the north direction, and where $(x(t_i),$
 $y(t_i))$ represents respectively the coordinates of the source in the same
 reference system.

Note that the system [20-21] of four equations with four unknowns $(x(t_R),$
 10 $y(t_R), \rho_A(t_R), \rho_B(t_R))$ accepts, in a known manner, a unique solution as long as
 the azimuths $\theta_A(t_R)$ and $\theta(t_R)$ are different.

Also note that here the antennas A and B are assumed fixed and therefore
 that (x_A, y_A) and (x_B, y_B) are independent from time;. However, an analogous
 method may apply to a system comprising mobile antennas, as long as their
 15 speed is known.

Subsequently, from relations [20] and [21], the following system is obtained
 by eliminating $x(t_R)$ and $y(t_R)$:

$$\begin{aligned} \sin \theta_A(t_R) \cdot \rho_A(t_R) - \sin \theta_B(t_R) \cdot \rho_B(t_R) &= -x_A + x_B \\ \cos \theta_A(t_R) \cdot \rho_A(t_R) - \cos \theta_B(t_R) \cdot \rho_B(t_R) &= -y_A + y_B \end{aligned} \quad [22]$$

then by deriving in relation to time:

$$\begin{aligned} \sin \theta_A(t_R) \cdot \dot{\rho}_A(t_R) - \sin \theta_B(t_R) \cdot \dot{\rho}_B(t_R) \\ = -\cos \theta_A(t_R) \cdot \rho_A(t_R) \cdot \dot{\theta}_A(t_R) + \cos \theta_B(t_R) \cdot \rho_B(t_R) \cdot \dot{\theta}_B(t_R) \end{aligned}$$

and [23]

$$\begin{aligned} \cos \theta_A(t_R) \cdot \dot{\rho}_A(t_R) - \cos \theta_B(t_R) \cdot \dot{\rho}_B(t_R) \\ = \sin \theta_A(t_R) \cdot \rho_A(t_R) \cdot \dot{\theta}_A(t_R) - \sin \theta_B(t_R) \cdot \rho_B(t_R) \cdot \dot{\theta}_B(t_R) \end{aligned}$$

Thus, a system with two equations with two unknowns $\dot{\rho}_A$ and $\dot{\rho}_B$ is obtained, accepting in a known manner a unique solution as long as θ_A is different from θ_B .

To solve the system [21] and determine the values of $\dot{\rho}_A$ and $\dot{\rho}_B$ it is
 5 necessary to know not simply the measurements of azimuths θ_A and θ_B , but also the values of the variations $\dot{\theta}_A$ and $\dot{\theta}_B$ of these azimuths over time. $\dot{\theta}_A$ and $\dot{\theta}_B$ may be determined by different known methods, of which two corresponding to the preferred implementation mode are presented below.

10 According to a preferred first form of this second implementation mode of the procedure according to the invention, $\dot{\theta}_A$ and $\dot{\theta}_B$, are determined during step 22, by separately applying to the azimuth measurements obtained on antennas A and B a Kalman filter with dynamics order 1 (status vector $(\theta_B; \dot{\theta}_B)$). Thus linearization of the law of variation of these
 15 measurements is made.

In addition, an estimation of frequencies related to source movement in relation to antennas A and B is made by applying to frequency measurements f_A and f_B a Kalman filter with a dynamics order 0 (with as status vector $X = (f)$). Thus, smoothing is obtained during measured f_A and f_B
 20 frequency time.

Subsequently, the output from these filters obtained is an estimation at current moment of magnitudes $(\theta_A, \theta_B, \dot{\theta}_A, \dot{\theta}_B, f_A, f_B)$, estimation used during the next step to determine the values $\dot{\rho}_A$ and $\dot{\rho}_B$ of the radial speeds.

25 According to a second preferred form of this implementation mode, the determination of $\dot{\theta}_A(t_R)$ and $\dot{\theta}_B(t_R)$ is obtained graphically. This form is in particular applicable in the case where means are available making it possible to represent measurement of signals received in an azimuth/time or frequency/time reference system on a screen, so as to have graphic
 30 representations such as those illustrated in figures 5 and 6.

In this type of case, a representation of measurements 51, 61 of the received signal is available, made at consecutive moments t_i , from which it is possible using graphic tools such as mobile cursors 52 and 62, to determine in the best manner by smoothing or "visual filtering" the value of magnitudes
 35 $(\theta_A, \theta_B, \dot{\theta}_A, \dot{\theta}_B, f_A, f_B)$ at a reference moment t_R . These magnitudes are

deduced from the positions and orientations of cursors in the view planes considered.

The potential values of $\dot{\rho}_A(t_R)$ and of $\dot{\rho}_B(t_R)$ and the corresponding
 5 values of $f_A(t_R)$ and $f_B(t_R)$ are thus determined, then step 23 consists, in this second implementation mode of the procedure according to the invention, in searching which of these values minimizes the criterion Δ defined by the following relation:

$$10 \quad \Delta = |f_{0A} - f_{0B}| = \left| f_A(t_R) / \left(1 - \frac{\dot{\rho}_A(t_R)}{c} \right) - f_B(t_R) / \left(1 - \frac{\dot{\rho}_B(t_R)}{c} \right) \right| \quad [24]$$

where f_{0A} and f_{0B} represent the estimations of frequency f_0 of the signal when
 emitted (i.e. without Doppler effect), produced using measurements
 respectively related to the signal received on antenna A and the signal
 15 received on antenna B.

In the assumption where the potential values considered of $\dot{\rho}_A(t_R)$ and
 $\dot{\rho}_B(t_R)$ and the values of $f_A(t_R)$ and $f_B(t_R)$ correspond to the real location of the
 sources, the two values of the emitted frequency f_{0A} and f_{0B} obtained are
 20 similar and only differ one from the other due to measurement errors. The value of Δ is then minimal.

On the other hand, in the assumption where the potential values considered
 for $\dot{\rho}_A(t_R)$ and $\dot{\rho}_B(t_R)$ and $f_A(t_R)$ and $f_B(t_R)$ correspond to a ghost source,
 these two values f_{0A} and f_{0B} are appreciably different so that Δ is not minimal.
 25 Thus, the ambiguity affecting measurements made by antennas is clearly eliminated.

For the ease of understanding of the description, the different steps of
 the procedure according to the invention have been described in the two
 30 modes and for all their variants in the specific case where the system is in the presence of a single source in the monitored zone. Naturally, this specific case does not define the limit of the scope of the invention; it may be implemented advantageously to eliminate the ambiguity concerning the real position of several distinct sources moving in the monitored zone.

CLAIMS

1. Process for the elimination of ghost sources from a passive sonar comprising at least two linear antennas A and B, characterized in that it comprises at least:

An initial acquisitions step (21), during which the signal received is measured for the different moments of measurement t_i , and where it is determined, for each antenna, the Doppler frequency f , of the signal received, as well as the possible values of the azimuth θ of the source,

A second step (22) for determining the potential values of the source speed, as this step is performed using the measured azimuth θ and frequency f values,

A third step (23) eliminating the ambiguity and rejection of ghost sources during which, for the potential sources, the frequency and speed values are determined satisfying, for each moment t_i of measurement, the measurement equations linking the frequency of the signal received to the frequency f_0 emitted by the source, at the source speed and position.

2. Process according to claim 1, in which the measurement equations used during the third step (23) are expressed as follows:

$$f_A(t_i) = f_0 [1 - (v_x \cdot \sin \theta_A(t_i) + v_y \cdot \cos \theta_A(t_i)) / c]$$

and

$$f_B(t_i) = f_0 [1 - (v_x \cdot \sin \theta_B(t_i) + v_y \cdot \cos \theta_B(t_i)) / c]$$

where c represents here the celerity of sound, assumed known, v_x and v_y representing the components of the speed $\vec{V}$ of the source in the Cartesian reference system, f_A , f_B , θ_A and θ_B the values of the frequency of the received signal and the azimuth measured for each of the two antennas A and B

3. Process according to claim 2, in which, during the determination step(22) the components v_x and v_y of the source speed are determined by triangulation.
4. Process according to claim 2, in which the possible values of components v_x and v_y of the source speed are estimated by making a series of N measurements of the signal received by each antenna, at consecutive movements t_i , respectively in directions $\theta_A(t_i)$ and $\theta_B(t_i)$, by defining a status vector $X=[f_0; f_0v_x; f_0v_y]^T$, and by resolving the linear equation systems represented by the relation below by means of the least square technique:

$$F = M. X,$$

where M represents a measurement matrix with 2N lines in which the expression for each line is:

$$M_A(t_i) = [1; -\sin\theta_A(t_i)/c; -\cos\theta_A(t_i)/c]$$

or

$$M_B(t_i) = [1; -\sin\theta_B(t_i)/c; -\cos\theta_B(t_i)/c],$$

each line $M_A(t_i)$ or $M_B(t_i)$ corresponding to a measurement moment t_i ,

and where F represents a vector with 2N components consisting of the measurement pairs $(f_A(t_i), f_B(t_i))$ of the frequencies of the signal received by each antenna, measured at N moments t_i .

5. Process according to one of the claims 2 to 4, in which the third coherence evaluation step (23) consists in:

- calculating, for each moment t_i considered, the value of the magnitude v^m defined by the relation:

$$v^m(t_i) = (f_A(t_i) - f_B(t_i)) / (f_A(t_i) + f_B(t_i))$$

where $f_A(t_i)$ and $f_B(t_i)$ represent the frequency measurements of the signal received by each of the antennas at measurement moment t_i ,

- calculating, for each potential source, the value of the magnitude v defined by the relation:

$$v(t_i) = \frac{v_x \cdot (\sin \theta_A(t_i) - \sin \theta_B(t_i)) + v_y \cdot (\cos \theta_A(t_i) - \cos \theta_B(t_i))}{v_x \cdot (\sin \theta_A(t_i) + \sin \theta_B(t_i)) + v_y \cdot (\cos \theta_A(t_i) + \cos \theta_B(t_i)) - 2c}$$

where $\theta_A(t_i)$ and $\theta_B(t_i)$ represent the azimuths measured at moment t_i considered and allocated to the potential source considered,

- calculating, for each potential source, the deviation value $v - v^m$

the source being considered as real is then the one for which the deviation $v - v^m$ is the smallest.

6. Process according to claim 1, in which the second step (22) consists of applying an extended Kalman filter to the status vector $X = [x; v_x; y; v_y; f_0]$ subject to a certain status noise defined, a priori, to estimate the possible values of Cartesian components of the speed of the source emitting the measured signal and the corresponding frequency of the emitted signal.
7. Process according to claim 6, in which the measurement equations used during the third step (23) are expressed as follows:

$$\theta_A = A \tan \frac{x_A}{y_A}$$

and

$$\theta_B = A \tan \frac{x_B}{y_B}$$

for the measured azimuth,

$$f_A(t_i) = f_0 [1 - (v_x \cdot \sin \theta_A(t_i) + v_y \cdot \cos \theta_A(t_i)) / c]$$

and

$$f_B(t_i) = f_0 [1 - (v_x \cdot \sin \theta_B(t_i) + v_y \cdot \cos \theta_B(t_i)) / c]$$

for the frequency measurements.

8. Process according to claim 7, in which the third step consists of testing the frequency residual made up by the deviations between frequencies $[f_A(t_i), f_B(t_i)]$, calculated using estimated values of the speed and values of azimuths at moment t_i , and the values $[f_A^m(t_i), f_B^m(t_i)]$ measured on samples of signals received at different moments t_i , the real position of the source is that for which the residuals obtained are those mostly centered around zero.
9. Process according to claim 1, in which the measurement equations used during the third step (23), are expressed as follows at any moment t :

$$f_A(t) = f_0 [1 - \dot{\rho}_A(t) / c]$$

and

$$f_B(t) = f_0 [1 - \dot{\rho}_B(t) / c]$$

10. Process according to claim 9, in which the values $\dot{\rho}_A(t_R)$ and $\dot{\rho}_B(t_R)$ (t_R reference moment) are determined using the equation system:

$$\begin{aligned} & \sin \theta_A(t_R) \cdot \dot{\rho}_A(t_R) - \sin \theta_B(t_R) \cdot \dot{\rho}_B(t_R) \\ &= -\cos \theta_A(t_R) \cdot \rho_A(t_R) \cdot \dot{\theta}_A(t_R) + \cos \theta_B(t_R) \cdot \rho_B(t_R) \cdot \dot{\theta}_B(t_R) \\ & \cos \theta_A(t_R) \cdot \dot{\rho}_A(t_R) - \cos \theta_B(t_R) \cdot \dot{\rho}_B(t_R) \\ &= \sin \theta_A(t_R) \cdot \rho_A(t_R) \cdot \dot{\theta}_A(t_R) - \sin \theta_B(t_R) \cdot \rho_B(t_R) \cdot \dot{\theta}_B(t_R) \end{aligned}$$

where $\dot{\theta}_A$ and $\dot{\theta}_B$ represent the values of the law of variations of azimuth measurement θ_A and θ_B over time.

11. Process according to claim 10, in which $\dot{\theta}_A(t_R)$ and $\dot{\theta}_B(t_R)$ are determined by Kalman filtering.
12. Process according to claim 10, in which $\dot{\theta}_A(t_R)$ and $\dot{\theta}_B(t_R)$ are determined by means of a graphics method,
13. Process according to any one of claims 9 to 12, in which the real position of the source detected is defined by the radial speed values $\dot{\rho}_A(t_R)$ and $\dot{\rho}_B(t_R)$ and frequency $f_A(t_R)$ and $f_B(t_R)$ values minimizing a likelihood criterion Δ defined by:

$$\Delta = |f_{0A} - f_{0B}| = \left| f_A(t_R) / \left(1 - \frac{\dot{\rho}_A(t_R)}{c} \right) - f_B(t_R) / \left(1 - \frac{\dot{\rho}_B(t_R)}{c} \right) \right|$$

where f_{0A} and f_{0B} represent the estimations of the frequency f_0 of the emitted signal, obtained using measurements respectively relative to the signal measured by antenna A and the signal measured by antenna B.