

SET MODE PASSIVE LOCATION IN TOA/TDOA MODES

FIELD OF THE INVENTION

The present invention addresses the resolving of the problems associated with the passive location of targets in TOA (Time Of Arrival) or TDOA (Time Difference Of Arrival) mode.

5

For TOA, the invention makes it possible to locate any target by analyzing the arrival times, on one and the same receiver, of the waves transmitted by one or more transmitters and reflected by the target.

For TDOA, the invention makes it possible to locate a transmitting
10 target by measuring differences of arrival time of the transmitted wave on a number of receivers that are synchronized and scattered in space.

The present invention relates more particularly (but not exclusively) to the field of passive radars.

15

By its generic nature, the present invention also addresses all the mode combinations (multiple TOA, multiple TDOA, or even mixed TOA/TDOA).

20 CONTEXT OF THE INVENTION - PRIOR ART

The basic principle of the passive location methods, whether in TOA or TDOA mode, is to determine the positioning of targets by using the information supplied simultaneously by different information sources.

In TOA mode, or "Time Of Arrival" mode, interest is focused on the
25 signals transmitted by one or more transmitters and the same signals reflected by a target. The measurement, for a given transmitter, of the delay between the forward path (transmitter → receiver) and the reflected path (transmitter → target → receiver) is used to define a location curve (or a surface if the problem is dealt with in 3D) that takes the form of an ellipse or
30 an ellipsoid.

Thus, if a number of transmitters are analyzed simultaneously, and provided that there is the capability to receive the forward and reflected paths, it is possible to determine the position of the target that is sought by determining

the mutual points/areas of intersections of the different location curves/surfaces.

In TDOA mode, or "Time Difference Of Arrival" mode, interest is
5 focused on the location of transmitting targets by means of a number of
synchronized receivers (at least two), a main receiver and one (or more)
secondary receivers. As in the TOA mode, the position of the transmitting
target is then determined geometrically from location curves (hyperbolas or
hyperboloids) established from the measurements of the delays between the
10 different signals originating from the target and arriving at different instants
on each of the receivers.

One of the problems raised by passive location stems from the taking-into-
account of the uncertainty of the measurement delivered by the receivers. In
15 practice, to produce an accurate location of the target, it is necessary to know
as accurately as possible the location area that is compatible with the
uncertainties affecting the measurements. Consequently, the location curves
are in reality location areas, each area being situated between two extreme
curves, the spacing of which depends on the accuracy of the receivers. That
20 way, the points of intersections of the different location curves ideally
obtained by using a number of transmitting sources (TOA mode) or a number
of receivers (TDOA mode) are replaced in practice by areas of intersection
within which these points are situated.

Then, the search for the location areas that are compatible with the
25 measurements firstly involves the mathematical characterization of said
areas followed by the search for them in a space of interest (i.e. the space in
which the presence of a target is sought).

The usual methods used to perform this search are generally grid methods
30 which involve finely meshing all the space in which the targets are sought,
that is, a space that is vast enough to contain the area of uncertainty and
systematically analyzing each mesh to check whether it belongs to the
location area. There are also algebraic methods of the least-square type, or
even probabilistic methods, the complexity (and therefore the complexity of
35 implementation) of which increases with the number of information sources.

Apart from the grid methods, none of these methods provides a way of finely restoring the areas of uncertainties associated with the measurement errors (they give only error ellipses or ellipsoids). In addition, the grid methods require a large computation capability to process each mesh sufficiently quickly and determine the location area sufficiently quickly.

DESCRIPTION OF THE INVENTION

One aim of the invention is to benefit from the advantages of the grid processing operations notably in terms of resolution, yet without suffering the drawbacks thereof.

To this end, the subject of the invention is a method of passively locating a target in TOA or TDOA mode that implements a successive subdivision into blocks of an initial space (in which a target is to be located). The set of blocks is analyzed iteratively. On each iteration, each block of interest is subdivided into smaller identical subblocks. A block of interest is, according to the invention, a block in which at least one point belongs to the location area being sought. The iterative process is stopped when the size (resolution) of the subblocks obtained on the current iteration corresponds to the desired resolution.

The set of blocks resulting from this process provides an approximation of the shape of the location area that is sought (if the latter exists in the initial space).

More specifically, its subject is a method of passively locating a target in TOA or TDOA mode implementing a successive subdivision into blocks of an initial space (in which a target is to be located) and a search within each block for the presence of points belonging to the location area being sought. This invention is also characterized by the fact that the subdivision and the search are performed in the form of iterative steps on a selection of candidates blocks, modified on each iteration, so that, on each iteration, the blocks of the selection obtained on completion of the preceding iteration are searched to find the blocks containing at least one point belonging to the location area being sought. The blocks not containing any point are subsequently excluded from the selection, whereas the blocks containing at

least one point are re-subdivided into subblocks and replaced in the selection by the duly formed subblocks. The selection obtained on each iteration defines the location area with a resolution that increases on each iteration.

5 According to the invention, the iterations are stopped when the subblocks forming the selection define the location area with the desired resolution.

10 The method according to the invention also comprises an initialization step in which a first block $[X_0]$ is defined that corresponds to an "a priori" search space, this block constituting the initial selection.

According to a preferred embodiment, the method according to the invention mainly comprises :

- 15 - an initialization step in which a first block $[X_0]$ is defined that corresponds to an a priori search space and that leads to the formation of an initial list L_0^0 formed from the block $[X_0]$,
- an iterative step consisting in :
- 20 - subdividing each block $[X_n]$ of the current list L_0^{i-1} into four adjoining subblocks $[X_n^1]$, $[X_n^2]$, $[X_n^3]$ and $[X_n^4]$,
- searching for and selecting from the duly constituted subblocks those containing at least one point forming part of the location area,
- updating the current list to obtain a list L_0^i in which :
- 25 -a) the blocks $[X_n]$ for which no subblock has been selected are deleted,
- b) the other blocks are replaced by the selected subblock $[X_n^j]$,

the iterative step also includes an operation to compare the size $\Delta^{L_0^i(1)}$ of the blocks constituting the list L_0^i , the method being stopped when the size $\Delta^{L_0^i(1)}$ is greater than the desired resolution objective Δ^{obj} .

30

According to this embodiment, a block $[X_n^j]$ is selected if at least one of its points satisfies the criterion defined as follows :

$$- 0 \in J([X^i]) \text{ with } J([X^i]) = \left[\frac{[x^i]^2}{[a]^2} + \frac{[y^i]^2}{[b]^2} - 1 \right] \quad \text{in "TOA 2D" mode,}$$

$$- 0 \in J([X^i]) \text{ with } J([X^i]) = \left[\frac{[x^i]^2}{[c]^2} - \frac{[y^i]^2}{[d]^2} - 1 \right] \quad \text{in "TDOA 2D" mode,}$$

$$5 \quad - 0 \in J([X^i]) \text{ with } J([X^i]) = \left[\frac{[x^i]^2}{[a]^2} + \frac{[y^i]^2}{[b]^2} + \frac{[z^i]^2}{[b]^2} - 1 \right] \quad \text{in "TOA 3D" mode,}$$

$$- 0 \in J([X^i]) \text{ with } J([X^i]) = \left[\frac{[x^i]^2}{[c]^2} - \frac{[y^i]^2}{[d]^2} - \frac{[z^i]^2}{[d]^2} - 1 \right] \quad \text{in "TDOA 3D" mode.}$$

The invention relies on the set mode approach used to locate the target. The measurements deriving from the various sensors are modeled by
 10 intervals (i.e., they include a bounded error). Knowing these measurements, the invention uses an iterative process based on an ad hoc set mode criterion (i.e. dependent on the problem, TOA/TDOA single/multiple sensors) to find and approach with the desired resolution, all the areas of the space that are likely, in light of the measurements, to contain a target. The location
 15 is set mode in the sense that the invention provides a solution set to the location problem (i.e., a set of target positions guaranteed to contain the true position of the target).

Unlike a grid method, there is no need to mesh all the space, the iterative process used in the invention makes it possible to concentrate directly on the
 20 regions of interest.

DESCRIPTION OF THE FIGURES

The features and benefits of the invention will be better appreciated from the description that follows, which explains the invention through a
 25 particular embodiment taken as a nonlimiting example and based on the appended figures, which represent :

- figure 1, a typical single-transmitter geometrical configuration for implementing the TOA mode,
- figure 2, a representation of the set of location curves ideally

obtained in TOA mode with three transmitting sources,

- figure 3, a typical two-receiver geometrical configuration for implementing the TDOA mode,

- figure 4, a representation of the set of location curves ideally
5 obtained in TDOA mode with three secondary receivers,

- figure 5, the representation of a location area actually obtained in TOA mode with one transmitting source,

- figure 6, the representation of a location area actually obtained in TDOA mode with one receiver,

- 10 - figure 7, a theoretical flow diagram of the method according to the invention,

- figure 8, an illustration of the application of the method according to the invention to the TOA 2D mode with a single-transmitter system,

- figure 9, an illustration of the application of the method according to
15 the invention to the TDOA 2D mode with a single secondary receiver system,

- figure 10, an illustration of the application of the method according to the invention to the TOA 2D mode with a two-transmitter system, and

- figure 11, an illustration of the application of the method according to the invention to the TDOA 2D mode with a two secondary receivers system.

20

DETAILED DESCRIPTION

Interest is focused initially on figure 1 which schematically shows the ideal operating principle of the TOA location mode. In the interest of clarity of the explanation, the model illustrated here is a two-dimensional model
25 corresponding to the analysis of the signals obtained from a single transmitter (2D single-transmitter model).

As the figure illustrates, this "single transmitter" operating mode involves a transmitting source 12 (transmitter), a receiver 11, and a target 13 that is to be located. To locate the target, the receiver 11 measures the time
30 delay that exists between the received wave originating directly from the transmitter 12 (forward wave), and the received wave originating from the reflection of the wave transmitted by the source 12, on the target 13 that is to be located (reflected wave).

35 In such a configuration, if the distance between the transmitting source 12

and the receiver 11 is denoted L , the distance between the source 12 and the target 13 R_T and the distance between the target and the receiver R_R , the location of the target 13 involves measuring the delay between the forward and reflected waves and determining from this delay, by any known
 5 appropriate method, the distance R_b traveled by the reflected wave, defined by :

$$R_b = R_T + R_R$$

The target 13 is then located as illustrated by the curve 21 of figure 2 on an
 10 ambiguity ellipse, the foci 22 and 23 of which are the position of the transmitting source 12 and that of the receiver 11, and the major axis (semi-major axis) of which has the length $R_b/2$.

Consequently if a Cartesian frame of reference xOy is defined that is
 15 centered on the middle of the line segment $[R_x, T_x]$ 14 linking the source 12 and the receiver 11, and the vector $\vec{Ox}$ of which is collinear to the vector $\overrightarrow{R_x T_x}$, the equation of this location ellipse 21 in the frame of reference xOy is expressed by the following equation :

$$20 \quad \frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad [1]$$

with :

$$a = R_b/2$$

$$\text{and } b = \sqrt{a^2 - L^2/4}$$

25

To refine the location of the target 13, it is obviously necessary to have a number of transmission sources. That way, for one and the same target 13, a location ellipse can be associated with each source, the intersections of these ellipses defining the possible positions of the source to be located. The
 30 curves 21 and 24 of figure 2 illustrate the results obtained with a "2D two-transmitter" configuration from which two location ellipses are obtained, the foci 22, 23 and 25 of which are respectively the receiver and the first source for the ellipse 21, and the receiver and the second source for the ellipse 24. The set of the possible places of location of the target 13 then comprises the

two points of intersection 26 and 27 of the two curves.

Consequently, to determine the position of the target 13 without ambiguity, it is necessary to have at least one additional transmitting source ("2D multiple-transmitter" configuration), the intersection of the three location ellipses 21, 24 and 28 defining a single common point, the point 26 for example, on which the target 13 is situated.

Interest is then focused on figure 3 which schematically shows the ideal operating principle of the TDOA location mode. In the interest of clarity of the explanation, the model illustrated here is, as for the TOA mode presentation, a two-dimensional model corresponding to the analysis of the signals obtained from a transmitting target 31 and received by two receivers 32 and 33 distant from each other, a reference receiver, called main receiver, and a so-called secondary receiver, synchronized on the reference receiver (2D single secondary receiver model).

As illustrated by figure 3, this "secondary single-receiver" operating mode involves a transmitting target 31 (transmitter) that is to be located, a reference receiver 32, and a secondary receiver 33. To locate the target, the time delay that exists between the instant of reception by the reference receiver of the wave transmitted by the target 31 and the instant of reception of this same wave by the secondary receiver 33 is then analyzed.

In such a configuration, if the distance between the two receivers 32 and 33 is denoted L , the distance between the transmitting target 31 and reference receiver 32 is denoted R_R and the distance between the transmitting target 31 and the secondary receiver 33 is denoted R_{R1} , the location of the target 31 consists in measuring the delay between the waves received by the two receivers and determining from this delay, by any known appropriate method, the difference in distance traveled R_{d1} defined by :

$$R_{d1} = R_{R1} - R_R$$

The target 31 is then located as illustrated by the curve 41 of figure 4 on a hyperbola having foci 42 and 43 which are the position of the reference receiver and that of the secondary receiver and for which the distance

between peaks has the value $R_{d1}/2$.

Consequently, if a Cartesian frame of reference xOy is defined that is centered on the middle of the line segment $[R_x, R_{x1}]$ 34 linking the reference receiver 32 and the secondary receiver 33, and the vector $\vec{Ox}$ of which is collinear to the vector $\overrightarrow{R_x R_{x1}}$, the equation for this location hyperbola 41 in the frame of reference xOy is expressed :

$$\frac{x^2}{c^2} - \frac{y^2}{d^2} = 1 \quad [2]$$

with :

$$c = R_{d1}/2$$

$$\text{and } d = \sqrt{L^2/4 - c^2}$$

To refine the location of the target 31, it is obviously necessary to have a number of secondary receivers. That way, for one and the same target 31, a location hyperbola can be associated with each reference receiver/secondary receiver pairing. The intersections of these hyperbolas then define the possible positions of the target. The curves 41 and 44 of figure 4 illustrate the results obtained with a "2D two secondary receivers" configuration from which two location hyperbola are obtained, the foci 42, 43 and 45 of which are respectively the reference receiver R_x and the secondary receiver R_{x1} for the hyperbola 41 and the reference receiver R_x and a second secondary receiver R_{x2} for the hyperbola 44. The set of possible places of location of the target 31 then comprises the points of intersection 46 and 47 of the two curves.

Consequently, to determine the position of the target 31 without ambiguity it is necessary to have at least one additional secondary receiver ("2D multiple secondary receivers" configuration), the intersection of the three location hyperbola 41, 44 and 48 defining a single common point, the point 46 in the example, on which the target 31 is situated.

The theoretical determination principle explained in the preceding paragraphs through a two-dimensional location ("2D" location) can naturally be extended to a location in space (i.e. in 3D location).

In TOA mode, the location ellipse in "single-transmitter" mode is replaced by an ellipsoid in space, an ellipsoid which can be represented by the following equation :

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{b^2} = 1 \quad [3]$$

5 with :

$$a = R_b/2$$

$$\text{and } b = \sqrt{a^2 - L^2/4}$$

10 Similarly, in TDOA mode, the location hyperbola in "single secondary receiver" mode is replaced by a hyperboloid in space, a hyperboloid which can be represented by :

$$\frac{x^2}{c^2} - \frac{y^2}{d^2} - \frac{z^2}{d^2} = 1 \quad [4]$$

15 with :

$$c = R_{d1}/2$$

$$\text{and } d = \sqrt{L^2/4 - c^2} .$$

20 Interest is now focused on figures 5 and 6 which illustrate, through simple location scenarios in TOA 2D mode (figure 5) and in TDOA 2D mode (figure 6), the problem raised by the accuracy of the real measurements obtained with the receivers.

25 Like any measuring device, the receivers used by the passive location systems provide measurements that are marred by a certain inaccuracy that can be assumed to be bounded. This inaccuracy means that the distance measurements performed in TOA or TDOA mode are represented, no longer by exact values, but by intervals, the size of which corresponds to the
30 maximum measurement error. These intervals $[x]$ are defined by the following equation :

$$[x] = [x^-, x^+] = \{x \in \mathbb{R} / x^- \leq x \leq x^+\} \quad [5]$$

in which $\Re$ represents the set of real numbers.

If σ_{R_b} represents the maximum error on the measurement R_b in TOA mode, a measurement of R_b with bounded error is defined by the interval :

$$[R_b^-, R_b^+] := [R_b - \sigma_{R_b}, R_b + \sigma_{R_b}] \quad [6]$$

Consequently, taking into account a bounded error on the measurement of R_b in "TOA 2D" mode leads to the target concerned being located not on a curve but on a location surface delimited by two confocal ellipses 51 and 52 of respective parameters R_b^- and R_b^+ , such as that illustrated in figure 5. This surface 53 can be described by the following parametrical form :

$$\left\{ (x, y) \in \Re^2 \mid 1 \in \frac{x^2}{[a]^2} + \frac{y^2}{[b]^2} \right\} \quad [7]$$

in which :

$$[a] = [R_b]/2$$

and
$$[b] = \sqrt{[a]^2 - L^2/4}$$

are evaluated by applying the interval computation rules.

Similarly, if a location is performed in space ("TOA 3D"), the taking into account of the bounded errors of the measurement of R_b leads to the location of the target concerned in a volume defined by two confocal ellipsoids, a volume that can be described by the following parametrical form :

$$\left\{ (x, y, z) \in \Re^3 \mid 1 \in \frac{x^2}{[a]^2} + \frac{y^2}{[b]^2} + \frac{z^2}{[b]^2} \right\} \quad [8]$$

As for the TOA mode, the taking into account of a bounded error on the measurement of R_{d1} in "TDOA 2D" mode leads to the location of the target concerned not on a curve but on a location surface delimited by two

confocal hyperbolas 61 and 62 of respective parameters R_{d1}^- and R_{d1}^+ defined by the interval $[R_{d1}^-, R_{d1}^+] := [R_{d1} - \sigma_{R_{d1}}, R_{d1} + \sigma_{R_{d1}}]$, such as that illustrated in figure 6. This surface 63 can be described by the following parametrical form :

5

$$\left\{ (x, y, z) \in \mathbb{R}^2 \mid 1 \in \frac{x^2}{[c]^2} - \frac{y^2}{[d]^2} \right\} \quad [9]$$

with :

$$[c] = [R_{d1}]/2$$

10 and $[d] = \sqrt{L^2/4 - [c]^2}$

In the case of a location in space ("TDOA 3D"), the taking into account of the bounded errors on the measurement of R_{d1} leads to the location of the target concerned in a volume defined by two confocal hyperboloids, a volume that
15 can be described, in a similar manner, by the following parametrical form :

$$\left\{ (x, y, z) \in \mathbb{R}^3 \mid 1 \in \frac{x^2}{[c]^2} - \frac{y^2}{[d]^2} - \frac{z^2}{[d]^2} \right\} \quad [10]$$

Interest is now focused on figure 7 which schematically shows the
20 principle of the method according to the invention. In order to make the explanation of the operating principle of the method according to the invention clearer, this principle is described here in detail for the particular case of the search for an area of a location by means of location systems of "single-transmitter" type (location in TOA mode) or "single secondary
25 receiver" type (location in TDOA mode).

The basic principle of the method involves a progressive refining of the location area. It consists in subdividing the space that is to be analyzed (i.e., the initial search block $[x_0] \times [y_0]$ into adjoining subblocks in which the presence
30 of a target is evaluated by means of an ad hoc criterion. The subblocks in which the presence of a target is confirmed are in turn subdivided and the others are rejected. The resulting iterative process is repeated as long as the

presence of a target is confirmed in the blocks currently being analyzed and a stop criterion (corresponding to a block width objective) is not reached.

To this end, the method according to the invention comprises a number of
5 steps :

- an initialization step 71,
- an iterative calculation step 72.

The initialization step 71 consists in defining an initial block, $[X_0]$,
10 corresponding to an a priori search space. In 2D mode, the following thus applies :

$$[X_0] = [x_0] \times [y_0],$$

and in 3D mode, the following applies :

15

$$[X_0] = [x_0] \times [y_0] \times [z_0].$$

The step 71 also involves initializing a list L_0 , of a size that varies during the implementation of the method, comprising the list of blocks to be studied. The
20 content of L_0 is initialized with $[X_0]$.

The step 71 then consists in defining a stop criterion for the method. This stop criterion is given here by the "objective" resolution Δ^{obj} with which it is desired to ultimately characterize the location area. This resolution is
25 naturally limited by the accuracy of the measurements supplied by the receivers, but it can be arbitrarily set within this limit. In 2D location mode, it is perhaps defined in a coordinate system xOy by $\Delta^{obj} = (\Delta_x^{obj}, \Delta_y^{obj})$.

The step 71 is followed by a step 72 carrying out an iterative
30 processing operation that includes two nested processing loops, a main loop 73 and a secondary loop 74.

The main loop 73 consists in updating the list L_0 established on initialization with the results of the processing carried out by the second loop. Thus, on
35 each iteration i of the main loop, there is a re-updated list L_0 available,

denoted L_0^i .

On each iteration, each block $[X_{0,k}^i] = L_0^i(k)$ forming the list L_0^i is subdivided into N adjoining subblocks ($N=4$ in 2D mode, $N=8$ in 3D mode) and grouped together in a list L_1 .

5

As for the secondary loop 74, this consists in eliminating from L_1 , the blocks that are incompatible with the location area being sought (that is, the blocks that do not validate the criterion).

10 Consequently, the element $[X_{0,k}^i]$ of L_0^i is replaced, in L_0^i , by the list L_1 .

According to the invention, the method is chosen to determine whether a subblock $[X^j]$ includes a portion of the location area consists in determining whether one or more points of the subblock belong to that area.

15 To do this in the "single-transmitter" or "single secondary receiver" systems, simply the quantity $J([X^j])$ is considered, which is defined according to the location mode concerned by :

$$\text{- in "TOA 2D" mode: } J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} - 1 \right] \quad [11]$$

$$20 \quad \text{- in "TOA 3D" mode: } J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} + \frac{[z^j]^2}{[c]^2} - 1 \right] \quad [12]$$

$$\text{- in "TDOA 2D" mode: } J([X^j]) = \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - 1 \right] \quad [13]$$

$$\text{- in "TDOA 3D" mode: } J([X^j]) = \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - \frac{[z^j]^2}{[e]^2} - 1 \right] \quad [14]$$

25

with $[X^j] = [x^j] \times [y^j]$ for the "2D" modes,

and $[X^j] = [x^j] \times [y^j] \times [z^j]$ for the "3D" modes.

Therefore, to verify if at least one point of a block $[X^j]$ belongs to the location area, it is sufficient, according to the invention, to check whether :

$$0 \in J([X^j]).$$

- 5 The main loop is intrinsically an endless loop for which it is necessary to determine a stop condition and an operation to test for the appearance of this stop condition. According to the invention, this stop condition is initialized in the step 71 and relates to the resolution Δ^{obj} with which it is desired to define the location area. Thus, the main loop 73 includes a test operation 75
10 executed at the end of processing on each iteration i . This condition is defined by the following equation :

$$\Delta^{L_0^{(1)}} \leq \Delta^{obj} \equiv \begin{cases} \Delta_x^{L_0^{(1)}} \leq \Delta_x^{obj} \\ \text{and} \\ \Delta_y^{L_0^{(1)}} \leq \Delta_y^{obj} \end{cases} \quad [11]$$

- 15 in which $\Delta^{L_0^{(1)}}$ represents the resolution of the first block forming the list L_0^i , each block of the list having an identical resolution at this stage.

Thus, as long as the condition of the equation [11] is found to be verified, the iterative calculation step 72 is repeated. The iteration stops only when the desired resolution is reached.

20

Thus, when applied to a two-dimensional TOA or TDOA location processing operation, and for an iterative subdivision of each block into $P = 4$ subblocks, the method according to the invention can be described by the following sequence of actions :

25

1. Definition of the initial size of an analysis cell (block) :
 $[X_0] = [x_0] \times [y_0]$.
2. Initialization of the list L_0 of the analyzed blocks: L_0^0 .
3. Definition of the stop criterion: $\Delta^{obj} = (\Delta_x^{obj}, \Delta_y^{obj})$.
- 30 4. **/beginning of main loop/**: (Formation of L_0^i)
5. For n varying from 1 to the size of the list L_0^{i-1}
6. subdivision of each block n into $P=4$ adjoining subblocks :

$$[X_n^1] = [x^-, (x^- + x^+)/2] \cdot [y^-, (y^- + y^+)/2]$$

$$[X_n^2] = [x^-, (x^- + x^+)/2] \cdot [(y^- + y^+)/2, y^+]$$

$$5 \quad [X_n^3] = [(x^- + x^+)/2, x^+] \cdot [y^-, (y^- + y^+)/2]$$

$$[X_n^4] = [(x^- + x^+)/2, x^+] \cdot [(y^- + y^+)/2, y^+]$$

7. creation of the list $L_1^n = \{ [X_n^1], [X_n^2], [X_n^3], [X_n^4] \}$

10 8. **/beginning of secondary loop/**

9. For j varying from 1 to 4

10. Elimination of the subblocks $[X_n^j]$, that do not satisfying the selection criterion $0 \in J([X_n^j])$: Formation of L_1^n .

11. - if L_1^n is not empty : replacement, in L_0^{i-1} , of the block $[X_n]$ by
15 the list L_1^n ,
- if L_1^n is empty : elimination of the block $[X_n]$ from the list L_0^{i-1}

12. **/end of secondary loop/**

13. **/end of main loop/** (Formation of L_0^i)

14. Calculation of the resolution of the first element of L_0^i :

$$20 \quad \Delta_{L_0^i(1)}^{L_0^i(1)} = \left(x_{L_0^i(1)}^+ - x_{L_0^i(1)}^-, y_{L_0^i(1)}^+ - y_{L_0^i(1)}^- \right)$$

15. - if $\Delta_{L_0^i(1)}^{L_0^i(1)} \leq \Delta^{obj}$: return to /start of main loop/
- else : end of procedure

16. **/end of procedure/**

25 The principle of implementation of the method according to the invention can be advantageously illustrated by figures 8 and 9.

Figure 8 illustrates the implementation of the method according to the invention on a location in TOA mode, with a "2D single-transmitter" type system.

30 As can be seen the figure, the implementation of the method according to the invention is physically embodied in a breakdown into blocks of the space that includes the location area 81. This subdivision forms a mesh of the space, a mesh in which each cell is analyzed to determine whether or not it includes a

portion of the location area. The duly formed mesh is refined iteratively. During the successive iterations, certain cells 83 formed by the division of a larger cell 82 including a portion 84 of the location area no longer include such portions. According to the invention, the process of refining these
 5 "empty" areas then ceases, which makes it possible advantageously to avoid continuing, for such cells, an analysis that is sterile and costly in computation workload and to concentrate the refining on the cells where it presents a benefit for determining as accurately as possible the location area 81. An irregular mesh is thus advantageously obtained, in which the tight mesh is
 10 only centered on the location area.

Figure 9 illustrates in the same way the implementation of the method according to the invention on a location in TDOA mode, with a system of the "2D single secondary receiver" type. The implementation of the method
 15 according to the invention is embodied in the same way by a subdivision into blocks of the space that includes the location area 91. Areas 93 are also obtained for which the refining is not carried out and areas 94 for which it is continued.

20 The method according to the invention, detailed in the preceding paragraphs for the particular case of systems of "TOA single-transmitter" or "TDOA single secondary receiver" types can obviously be applied to the more complex location systems of "TOA multiple transmitter" or "TDOA multiple secondary receiver" types in 2D or in 3D. These types of systems
 25 can be used, by considering the intersections of the different location areas, to refine the location of the target being sought by limiting the location area to the intersections of the different areas obtained.

Regarding these modes, the method according to the invention, as described in the foregoing, remains applicable in principle. Only the criterion for
 30 selection of a subblock used in the secondary loop of the step 72 of the iterative processing operation is modified. Thus, if the system includes a total number N of transmitters (location in "TOA multiple transmitter" mode) or receivers (location in "TDOA multiple secondary receiver" mode), a subblock [X] will be selected if the following equation is verified :

35

$$A = \sum_{j=1}^N a_j = N \quad [12]$$

in which each element a_j represents the result of the calculation of a selection criterion relating to a pairing (receiver R_x , transmitter T_x^i) (TOA location mode) or (reference receiver R_x , secondary receiver R_x^i) (TDOA location mode).

The elements a_j are defined by the following equations :

$$a_1 = \begin{cases} 1 & \text{if } 0 \in J_1([X]) \\ 0 & \text{else} \end{cases}$$

.....

$$a_N = \begin{cases} 1 & \text{if } 0 \in J_N([X]) \\ 0 & \text{else} \end{cases}$$

and in which $J_i([X])$ represents, for each individual system (R_x , T_{xj}) or (R_x , R_{xj}), the quantity $J([X])$ defined previously ([11, 12, 13, 14]).

The figures 10 illustrate the implementation of the method in the case of a location system of "TOA two-transmitters" type. As can be seen in the figure, the mesh produced using the method according to the invention is once again an irregular mesh for which the tight cells, of greater resolution, are located on the location areas 101 and 102 defined by each individual system, and more specifically on the portions 103 and 104 of these areas that constitute intersections and that represents the possible location areas of the target.

Turning to figure 11, this illustrates in a similar manner the implementation of the method in the case of a location system of the "TDOA two secondary receivers" type. As for the preceding case, it can be seen that the mesh produced by the method according to the invention comprises tight cells only in the places of the areas 113 and 114 representing the intersections of the location areas 111 and 112 defined by each individual system.

Since no system can be perfect, a certain tolerance can be accepted as to the number of basic criteria $J_n([X])$ that are simultaneously satisfied. This tolerance is reflected by an acceptance of an interval $[X]$ if $A \geq M$ (with $M \leq N$).

5

The present invention extends, by adapting the basic criteria $J_n([X])$:

10

- to the problems of multiple TOA location: use of a family of basic criteria combining the basic criteria associated with each of the TOA problems (this situation occurs when trying to locate a target by analyzing two receivers that are not co-located operating in TOA mode).
- to the problems of multiple-TDOA location: use of a family of basic criteria combining the basic criteria associated with each of the TDOA sub-problems.
- to the problems of mixed TOA/TDOA location: use of a family of basic criteria combining the basic criteria associated with each of the TOA and TDOA problems.

15

CLAIMS

1. A method of passively locating a target in TOA or TDOA mode implementing a meshing (subdivision) into blocks of the space in which the location area is situated and a search within each block for the presence or points belonging to this location area concerned,
 5 characterized in that the subdivision and the search are performed in the form of iterative steps on a selection of candidate blocks, modified on each iteration, so that, on each iteration, the blocks of the selection obtained on completion of the preceding iteration are searched to find the blocks containing at least one point belonging to the location area,
 10 the blocks not containing any point subsequently being excluded from the selection, whereas the blocks containing at least one point are re-subdivided into subblocks and replaced in the selection by the duly formed subblocks, the selection obtained on each iteration defining the location area with an accuracy that increases on each iteration.
 15
2. The method as claimed in claim 1, also comprising an initialization step in which a first block $[X_0]$ is defined that corresponds to an a priori search space, this block forming the initial selection.
- 20 3. The method as claimed in one of claims 1 or 2, in which the iterations are stopped when the subblocks forming the selection define the location area with the desired resolution.
- 25 4. The method as claimed in one of the preceding claims, characterized in that it comprises :
 - an initialization step (71) in which a first block $[X_0]$ is defined that corresponds to an a priori search space and that leads to the formation of an initial list L_0^0 formed from the block $[X_0]$,
 - an iterative step (72) consisting in :
 - 30 ▪ subdividing (73) each block $[X_n]$ of the current list L_0^{i-1} into four adjoining subblocks $[X_n^1]$, $[X_n^2]$, $[X_n^3]$ and $[X_n^4]$,
 - searching for and selecting (73) from the duly constituted

subblocks those containing at least one point forming part of the location area,

- updating (73) the current list to obtain a list L_0^i in which :
 - the blocks $[X_n]$ for which no subblock has been selected are deleted,
 - the other blocks are replaced by the selected subblocks $[X_n^j]$,

the iterative step comprising a test (75) for comparing the resolution $\Delta^{L_0^{(1)}}$ of the blocks constituting the list L_0^i , the method being stopped when the resolution $\Delta^{L_0^{(1)}}$ is greater than the desired resolution Δ^{obj} .

5. The method as claimed in claim 4, for which, in "TOA 2D single transmitter" location mode, a subblock $[X_n^j]$ is selected if it satisfies the criterion defined by :

$$- 0 \in J([X^j]) \text{ with } J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} - 1 \right].$$

6. The method as claimed in claim 4, for which, in "TDOA 2D single secondary receiver" location mode, a subblock $[X_n^j]$ is selected if it satisfies the criterion defined as follows :

$$- 0 \in J([X^j]) \text{ with } J([X^j]) = \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - 1 \right].$$

7. The method as claimed in claim 4, for which, in "TOA 3D single-transmitter" location mode, a subblock $[X_n^j]$ is selected if it satisfies the criterion defined as follows :

$$- 0 \in J([X^j]) \text{ with } J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} + \frac{[z^j]^2}{[b]^2} - 1 \right]$$

8. The method as claimed in claim 4, for which, in "TDOA 3D single

secondary receiver" location mode, a subblock $[X_n^j]$ is selected if at least one of its points satisfies the criterion defined as follows :

$$- 0 \in J([X^j]) \text{ with } J([X^j]) = \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - \frac{[z^j]^2}{[d]^2} - 1 \right].$$

5

9. The method as claimed in claim 4, for which, in "TOA multiple-transmitters" location mode or in "TDOA multiple secondary receivers" location mode, a subblock $[X_n^j]$ is selected if it satisfies the criterion A defined by the equation ;

10

$$- A = \sum_{j=1}^N a_j = N$$

in which N represents the number of transmitters or secondary receivers constituting the TOA or TDOA location system concerned and in which the terms a_j are defined as follows :

15

$$a_1 = \begin{cases} 1 & \text{if } 0 \in J_1([X]) \\ 0 & \text{else} \end{cases},$$

$$a_2 = \begin{cases} 1 & \text{if } 0 \in J_2([X]) \\ 0 & \text{else} \end{cases},$$

.....

20

$$a_N = \begin{cases} 1 & \text{if } 0 \in J_N([X]) \\ 0 & \text{else} \end{cases},$$

in which $J_i([X])$ represents, for each individual "single-transmitter" (R_x, T_{xj}) or "single secondary receiver" (R_x, R_{xj}) system, the quantity defined by :

25

$$- J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} - 1 \right] \text{ in "TOA 2D" mode,}$$

$$- J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} + \frac{[z^j]^2}{[b]^2} - 1 \right] \text{ in "TOA 3D" mode,}$$

$$\begin{aligned}
- J([X^j]) &= \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - 1 \right] \text{ in "TDOA 2D" mode,} \\
- J([X^j]) &= \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - \frac{[z^j]^2}{[d]^2} - 1 \right] \text{ in "TDOA 3D" mode.}
\end{aligned}$$

10. The method as claimed in claim 4, for which, in "TOA multiple-transmitters" location mode or in "TDOA multiple secondary receivers" location mode, for a number N of transmitters or secondary receivers constituting the TOA or TDOA location system concerned, a subblock $[X_n^j]$ is selected if it satisfies the criterion A defined by the equation :

$$- A = \sum_{j=1}^N a_j \geq M$$

in which M represents a determined number, less than N, of transmitters or secondary receivers constituting the TOA or TDOA location system concerned and in which the terms a_j are defined as follows :

$$a_1 = \begin{cases} 1 & \text{if } 0 \in J_1([X]) \\ 0 & \text{else} \end{cases},$$

$$a_2 = \begin{cases} 1 & \text{if } 0 \in J_2([X]) \\ 0 & \text{else} \end{cases},$$

.....

$$a_N = \begin{cases} 1 & \text{if } 0 \in J_N([X]) \\ 0 & \text{else} \end{cases},$$

in which $J_j([X])$ represents, for each individual "single-transmitter" (R_x, T_{xj}) or "single secondary receiver" (R_x, R_{xj}) system, the quantity defined by :

$$- J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} - 1 \right] \text{ in "TOA 2D" mode,}$$

$$- J([X^j]) = \left[\frac{[x^j]^2}{[a]^2} + \frac{[y^j]^2}{[b]^2} + \frac{[z^j]^2}{[b]^2} - 1 \right] \text{ in "TOA 3D" mode,}$$

$$\begin{aligned}
 - J([X^j]) &= \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - 1 \right] \text{ in "TDOA 2D" mode,} \\
 - J([X^j]) &= \left[\frac{[x^j]^2}{[c]^2} - \frac{[y^j]^2}{[d]^2} - \frac{[z^j]^2}{[d]^2} - 1 \right] \text{ in "TDOA 3D" mode.}
 \end{aligned}$$

5

11. An application of the method as claimed in claim 9 or 10 to the passive location of a target by a global system consisting of individual "single-transmitter" and "single secondary receiver" systems and operating in a mixed TOA/TDOA mode.