

METHOD AND DEVICE FOR ESTIMATING THE TRAJECTORY OF A MOVING OBJECT

The invention relates to a method for estimating the trajectory of
5 an object by measuring angles and the knowledge of the trajectory of a
system equipped with a means for measuring angles. It can be used to
determine the trajectory of objects which communicate by radio frequency
pathway with other devices in a radio communication network system. The
method is used notably to determine the parameters of the trajectory such as
10 the acceleration and other such parameters. The method is of use in the field
of radio goniometry.

The location of an object moving with a speed similar to that of a
detection system comes up against certain technical difficulties. The known
technique of location by density does not give satisfactory results notably
15 because of the similar speed between the object to be detected and the
detection system. It is known practice to use electrostatic sensors to
determine the trajectory of moving objects. It is also known practice to
employ optronics sensors to determine the trajectory with which an object is
moving.

20 Some methods known from the prior art, for example that
described in the patent FR 2833084, apply for the cases where the object for
which the trajectory is to be determined is moving according to a uniform
rectilinear movement.

In the opinion of the applicant, the techniques described in the
25 prior art are better suited to particular cases and do not provide any
trajectography method for more general applications, for non-rectilinear
trajectories: the prior art does not propose any method that makes it possible
to detect the type of trajectory followed by the object for which an estimation
of trajectory is to be obtained.

The method according to the invention relies notably on the use of a limited quantity of measurements of angles to estimate any trajectory of an object. The measurements are notably performed using a goniometer.

Hereinafter in the description, the full concept of deterministic observability is first recalled: “a system without state or measurement noise is considered to be completely observable over a time interval $[t_{ini} \ t_{fin}]$ if the measurements available during this period make it possible to obtain the initial state of the observed object uniquely.” Next, the concept of observability potential of a platform is introduced, corresponding to the capacity to detect movements of objects. This potential is directly linked to the movement of the system equipped with the sensor. Finally, “complexity of a trajectory” is the expression used to describe the minimum number of dimensions necessary to describe a given trajectory. For example, a point may be simply described by a triplet (x, y, z) or a complexity of 1. Also, a uniform rectilinear movement is fully characterized by an initial point (x_0, y_0, z_0) and an initial speed (v_{x0}, v_{y0}, v_{z0}) or a complexity of 2. There are many ways of compressing the information to describe a trajectory. As a matter of fact, the choice of the compression functions (for example the interpolation polynomials) has an impact on the complexity. “Compressive transformation” will be the expression used to denote any operation making it possible to compress the datum that the points of a trajectory represent. It must be noted that the compressive transformations are, essentially, non-bijective. The term “inverse transformation” will therefore be understood to mean the decompression of a trajectory from compressed parameters.

The invention relates to a method for estimating a trajectory of a first object by means of a moving platform equipped with means for measuring at least one angle between the first object and the platform according to a given direction comprising at least the following steps:

- determining a set of points corresponding to the trajectory of the platform for a given time interval $[t_1, \dots, t_N]$,
- acquiring a set of values of angles over the same time interval $[t_1, \dots, t_N]$,

- defining the complexity C_g of the trajectory of the platform by calculating the error existing between the points of the trajectory partitioned into a plurality of groups of points and points of the trajectory obtained by extrapolation after compression of the trajectory,
- 5 • determining, for the same time interval $[t_1, \dots, t_N]$, the complexity c_p of the trajectory of the first object from an estimated complexity value C_g of the trajectory of the platform and of the error calculated between values of angles $\theta = [\theta_1, \dots, \theta_N]$ measured and partitioned into K groups and values of angles obtained by extrapolation of an estimated trajectory of the object,
- 10 • comparing the value of the complexity C_g of the platform and, if the value of the complexity of the platform is greater than the value of the complexity c_p of the object, then estimating the trajectory of the object, otherwise, transmitting a signal or an information item to adjust the trajectory of the platform.
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The method can comprise the following steps:

- a) estimating the complexity C_g associated with the trajectory of the platform by distributing, for a defined complexity value, the points of the trajectory randomly in K groups, applying a compressive transformation and its inverse to a group of points to obtain a second group of points for each complexity, and extrapolating the points, then determining the error existing s_{1g} between the points defining the trajectory of the platform and the points obtained by extrapolation, reiterating these steps by working on a set of groups of points by random draw and without overlap, then defining a second error value s_{2g} ,
- 20 defining the minimum error value and the associated compressive transformation,
- 25
- b) estimating the complexity C_p of the trajectory of the moving object from an estimated complexity value of the platform, by constructing K groups of angles by random draw without repetition, for each group k, by applying an inverse compressive transformation in order to determine a first trajectory for the object and by extrapolating the value of the first trajectory for the time
- 30

indices specific to the group k , by reconstructing the values of angles observed by the platform if the object had followed this extrapolated second trajectory, and by calculating the value of the error to obtain a first score s_{1p} , then by reiterating these steps for a set of groups of angles obtained by a
 5 subdivision in the order of the indices of the angles and without overlap and for each chosen complexity value, in order to obtain a second score, defining the minimum value,

c) comparing the value of the complexity C_g of the trajectory of the platform and the value of the complexity C_p of the trajectory of the object and, if C_g is
 10 greater than C_p , then executing an algorithm for estimating the trajectory of the object, otherwise modifying the complexity of the trajectory of the platform.

The error values can be determined by using a quadratic error calculation method.

15 Values of angles are measured by goniometry or radio goniometry, for an object equipped with a transmitter.

In certain cases of use, a signature of the object is used in order to determine the angles.

According to one implementation of the method, the object is
 20 moving relative to the platform.

The invention relates also to a system for estimating a trajectory of a first object moving relative to a moving platform equipped with means for measuring at least one angle between the first object and the platform according to a given direction, characterized in that the platform comprises
 25 means adapted for executing the steps of the method according to the invention.

Other features and advantages of the method according to the invention will become more apparent on reading the following description of an exemplary embodiment given by way of illustration and in a nonlimiting
 30 manner with attached figures which represent:

- Figure 1, an exemplary system for implementing the method according to the invention,
- Figure 2, a representation in a reference frame x, y, z , of the parameters used to solve the problem of passive trajectography,
- 5 • Figure 3, a first block diagram representing the overall steps of the method according to the invention,
- Figure 4, a representation of the steps for determining the complexity of the trajectory of a platform equipped with an angle measuring device and a navigation platform,
- 10 • Figure 5, a representation of the steps making it possible to determine the complexity of a moving object.

The following description is given as an illustrative example and in a nonlimiting manner to estimate the trajectory of a moving object equipped with a radio frequency transmitter using a platform equipped with a radio

15 goniometer, the platform performing one or more manoeuvres leading to a movement whose complexity as defined previously becomes greater than that of the object. The method also makes it possible to indicate to the platform if its manoeuvre is sufficient to estimate the trajectory of the object and propose an idea of optimal manoeuvre in order to improve the object

20 locating accuracy. The method can be used in the case where it is estimated that the trajectory of an object can be represented by a point.

Figure 1 represents an exemplary system for implementing the method according to the invention. The system 1 comprises a first object 10 for which the trajectory is to be estimated, comprising a transmitter of signals

25 and a system 11 or platform equipped with a navigation unit 12 making it possible to know over time the trajectory of the platform and the position of a goniometer 13 or of a radio goniometer allowing for angle measurement. The platform comprises a sensor 14 receiving the signal from at least the observed object 10. The information from the navigation unit 12 and the

30 goniometry information supplied by the goniometer 13 is redirected to a module 15 of the platform 11. The module 15 comprises a processor 16

which is suitable for processing the angle measurements and for executing the steps implemented by the method according to the invention. The platform 11 is also provided with a memory space 17 for storing data. The method can also be used to estimate the trajectory of objects which do not have a transmitter, but which can be identified, and/or tracked, by means of a signature which is specific to them and which makes it possible to make an angle measurement relative to an observer.

The method according to a variant implementation comprises, in outline, for example, a first phase of initialisation during which will be determined the characteristics intrinsic to the radio goniometer, the characteristics of the problem to be observed, for example, the range of speeds of the objects to be observed, the range of distance to be covered around the platform, etc.).

A second active phase comprises, for example, the following steps:

- the acquisition of angle measurements is performed via the radio goniometer of the platform for a given duration T , and, the navigation data of the platform are collected in parallel over the same duration T ,
- from the navigation data, the movement of the platform equipped with the radio goniometer is characterized. This makes it possible to assess the capacity C_g of the platform to detect movements of more or less complex objects, or observability potential,
- the complexity C_p of the trajectory of the object is estimated by taking account of the measured angle values,
- the value of the complexity C_g of the trajectory of the platform and the value of the complexity C_p of the trajectory of the object are compared,
- if the value C_g is greater than C_p , then the trajectory of the moving object is estimated,
- if the value C_g is less than or equal to C_p , then it is possible to propose an adjustment of the manoeuvre of the platform in order to obtain an

observability potential sufficient to estimate the trajectory of the object, then the trajectory of the object is estimated.

Figure 2 illustrates the problem of the passive trajectography in a three-dimensional reference frame, the parameters used, with multiple
5 sensors and curvilinear, non-planar trajectory.

The problem of the trajectography posed in the present invention can be stated as follows: an object is considered for which there is a desire to know the trajectory with a radio transmission capability p and a platform provided with a radio goniometer g or receiver.

10 The notion of two-dimensional trajectory is defined as a set of continuous functions $t \in [0;1] \rightarrow C$ where C denotes the well-known body of complexes.

The trajectories of the transmitting object and of the receiving platform are defined in the continuous case:

$$15 \quad \begin{cases} p : t \rightarrow p(t) \\ g : t \rightarrow g(t) \end{cases}$$

The functions are sampled over N samples to obtain the discrete time values of the trajectory:

$$\begin{cases} \mathbf{P} = [\mathbf{p}_1, \dots, \mathbf{p}_N] \\ \mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_N] \end{cases}$$

where:

$$20 \quad \mathbf{p}_n = [x_n, y_n]^T \text{ with } [\]^T \text{ being the transposed operator.}$$

When $\mathbf{P}$ or $\mathbf{G}$ will be represented in bold and without index, the set of the positions at the instants of measurements of the angles is considered in the form of a matrix of dimension $2 \times N$.

An angle measurement function is defined between $\mathbf{p}_n$ and $\mathbf{g}_n$
25 relative to a fixed direction, for example magnetic north,

$$\theta_n = \angle(\mathbf{p}_n - \mathbf{g}_n)$$

The set of angle measurements is denoted $\theta = [\theta_1, \dots, \theta_N]$

A Gaussian additive noise η is added to the measurement of azimuths, the noisy sequence of measurements is as follows:

$$\hat{\theta} = \theta + \eta$$

The method according to the invention will make it possible to estimate the trajectory of a moving object $\mathbf{P}$ knowing the trajectory of the platform $\mathbf{G}$ and the values of angles $\hat{\theta}$:

$$(\mathbf{g}, \hat{\theta}) \xrightarrow{TPA} \hat{\mathbf{p}}$$

Figure 3 represents, in a block diagram, the main steps of the method according to the invention. The steps are executed in the module 15 of the platform 11. The method takes account of the positions of the goniometer $\mathbf{G} = [\mathbf{g}_1, \dots, \mathbf{g}_N]$, the directions of arrival $\theta = [\theta_1, \dots, \theta_N]$ of the signals received on the goniometer and the instants $[t_1, \dots, t_N]$ of measurements $= [\theta_1, \dots, \theta_N]$, values which are, for example, stored on the platform, 30. The method will characterize, 31, the movement of the goniometer of the platform by a type 1 cross validation method described hereinbelow, and determine the complexity C_g of the goniometer, 32. Then, the method will characterize, 33, the movement of the object for which the trajectory is to be known by taking account of the movement of the goniometer, the complexity of the goniometer or of the platform by a cross validation method 2. Next, the value of the complexity C_p of the trajectory of the object is compared to that of the trajectory of the goniometer C_g . If the goniometer has a trajectory complexity greater than that of the object to be observed, then, 34, 35, the method will determine the values of positions of the observed object for different instants. Otherwise, the method will transmit to the operator a signal or message warning it that the complexity of the trajectory of the platform is insufficient to make it possible to determine the trajectory of the object to be observed. The operator can then order the change of the trajectory of the platform.

Figure 4 schematically represents the steps of the method implemented for the type 1 cross validation making it possible to estimate the complexity C_g of the trajectory of the goniometer.

The method takes as input the measured positions of the goniometer at the
5 instants $[t_1, \dots, t_N]$ for the platform.

Let $G = [g_1, \dots, g_N]$ be the set of the positions of the goniometer,

the values of the possible complexities for the trajectory of the platform equipped with the goniometer are chosen from a set of complexity of the trajectory defined by a user and the desired application, $[1, \dots, C_{gmax}]$.

10 For each compressive transformation T , the steps described below will be executed. The compressive transformations can be chosen, for example, from a dictionary. It is possible to compress in the Fourier space: this space is suited to circular trajectories. Generally, the compressive transformation will be chosen as a function of the assumed trajectory type (circular,
15 piecewise continuous, fractal, etc.).

a. Loop on the complexity

401- For each complexity C_g ranging from 1 to C_{gmax}

i. Construct K groups of size C_g from the set of the positions $G = [g_1, \dots, g_N]$
as follows: 402, 403 – randomly choose points from the set G and
20 distribute them in the K groups,

$\tilde{G} = [g_{J(1)}, \dots, g_{J(N)}]$, $\tilde{G}_k = [g_{H(1)}^k, \dots, g_{H(C_g)}^k]$. The distribution can be done with overlap of points between the groups: several groups may contain the same point. The random choice can be a random permutation.

25 The step with random partitioning into K groups with repetition/overlap between group leads to $\tilde{G}_k$.

ii. 404, for all the groups formed, k varying from 1 to K :

ii.1. Perform the compressive transformation from the C_g points of the kth group, the transformation will compress the trajectory according to C_g dimensions:

$\tilde{\mathbf{G}}_k \rightarrow \tilde{\mathbf{W}}_k$ which corresponds to the compressed version of the trajectory defined by the points contained in the kth group $\tilde{\mathbf{G}}_k$, 405,

ii.2. Perform the inverse compressive transformation to obtain a set of points $\hat{\mathbf{G}}_k$, 406,

ii.3. Extrapolate the points of $\hat{\mathbf{G}}_k$, 407, to all the available time indices $[t_1, \dots, t_N]$,

ii.4. Calculate, 408, the error between the duly extrapolated points and the points of the other groups which do not belong to $\hat{\mathbf{G}}_k$, the calculation being able to be a quadratic error calculation, a first score s1g (sum of the quadratic errors) is obtained, 409, for each group and for each complexity value.

Randomly partition, 410, $\tilde{\mathbf{G}} = [g_{L(1)}, \dots, g_{L(N)}]$, 411, the trajectory $\mathbf{G} = [g_1, \dots, g_N]$ into K groups containing $\left\lfloor \frac{N}{K} \right\rfloor$ points without overlap,

$\tilde{\mathbf{G}}_k^\beta$ denotes these groups, $\tilde{\mathbf{G}}_k = \left[g_{L(1)}^k, \dots, g_{L(\left\lfloor \frac{N}{K} \right\rfloor)}^k \right]$,

iii. 412, for all the groups formed, k varying from 1 to K

413, on each complementary of the groups, points which do not belong to the group considered and denoted $\widetilde{\mathbf{G}}_k$,

iv.1. Perform the compressive transformation then its inverse to extrapolate, 414, 415, $\widetilde{\mathbf{G}}_k$ to $\widetilde{\mathbf{W}}_k$ then $\widetilde{\mathbf{W}}_k$ to $\widehat{\mathbf{G}}_k$,

iv.2. Calculate the quadratic error 416 between each of the complementary groups and the transformed group $\tilde{\mathbf{G}}_k^\beta$.

417, the score s_{2g} (sum of the quadratic errors) is obtained for all the groups and for all the assumed complexity values,

- b. 418, extract the final score s_{fg} for the platform linked to all the complexities by aggregating the two scores s_{1g} and s_{2g} ,
- 5 c. Choose the best score s_{mg} (the minimal score) and extract the pair (transform, C_g complexity of the trajectory of the platform) which minimizes the s_{mg} .

This estimated complexity value $\hat{C}_g$ will be used to determine the trajectory of the moving object.

- 10 In the error calculation, any method other than the quadratic error method can be used, without departing from the scope of the invention and doing so for all the error computation steps in the type 1 cross validation or in the type 2 cross validation.

Figure 5 represents the steps of the type 2 cross validation for the estimation of the complexity of the trajectory of the object.

The inputs of the block are as follows, 500:

- the angles $\theta = [\theta_1, \dots, \theta_N]$ estimated by the radio goniometer at the instants $[t_1, \dots, t_N]$,
- the positions $G = [g_1, \dots, g_N]$ of the goniometer at the instants $[t_1, \dots, t_N]$
- 20 • the estimated complexity of the goniometer $\hat{C}_g$ or a maximum complexity such that $C_{any} \leq \hat{C}_g$, value estimated in the type 1j cross validation step
- the compressive transformation type.

For each complexity C_p ranging from 1 to $\hat{C}_g$, 501

- 25 a. construct K groups of angles of size $\left\lfloor \frac{N}{K} \right\rfloor$. To construct these groups, the angles are drawn randomly from the set $\theta = [\theta_1, \dots, \theta_N]$ without repetition, 502,
- b. for each group k, k=1 to K, 503

- i. 504, perform the estimation of the trajectory of the object, by assuming a type of trajectory of complexity C_p , using the angles which are not in the k th group (complementary of the group k) and the positions of the goniometer at these instants,
 5 after inverse compressive transformation, an estimated trajectory $\hat{P}_k^{C_p}$ is obtained for the object and for a group k , for a complexity value,
- ii. 505, the estimated trajectory $\hat{P}_k^{C_p}$ is extrapolated to the time indices specific to the k th group of angles.
 For a complexity value, the complete trajectory $\tilde{P}_k^{C_p}$ is obtained,
- 10 iii. 506, from $\tilde{P}_k^{C_p}$ and from the trajectory of the goniometer, the angles that the goniometer would have estimated if the observed object had passed through all the points of the complete estimated trajectory $\tilde{P}_k^{C_p}$ are reconstructed,
- iv. 507, the quadratic error is calculated between the angles of the group k
 15 and the angles determined using C_p with the same time indices, a score is obtained for the pair (K, C_p) corresponding to this error,

$$score_{RMSI}(k, C_{\text{Hypothèse}})$$
- c. 508, once all the groups with C_p set have been processed, the score $s1p$ is obtained by averaging the scores on the pairs (k, C_p) ; then the method will,
- 20 d. 509, construct K groups of size $\left\lfloor \frac{N}{K} \right\rfloor$ from $[\theta_1, \dots, \theta_N]$. To construct these groups, the set of the measured angles $[\theta_1, \dots, \theta_N]$ is subdivided in the order of the indices and without overlap into K groups of size $\left\lfloor \frac{N}{K} \right\rfloor$,
- e. 510 for each group k , $k=1$ to K :
 - v. 511, perform the estimation of the trajectory using the angles which are
 25 not in the k th group (complementary of the group k) and the positions of the goniometer,
 after inverse compressive transformation of the estimate, a trajectory $\hat{D}_k^{C_p}$, is obtained,

vi. 512, the trajectory $\hat{D}_k^{C_p}$ is extrapolated to the time indices specific to the kth group of angles,

$\tilde{D}_k^{C_p}$ complete is obtained,

vii. 513, from $\tilde{D}_k^{C_p}$ and from the trajectory of the goniometer, the angles that the goniometer would have estimated if the observed object had passed through all the points of $\tilde{D}_k^{C_p}$ are reconstructed,

viii. 514, the quadratic error is calculated between the angles of the group k and the angles determined using $\tilde{D}_k^{C_p}$ with the same time indices.

Another type of score $score_{RMS2}(k, C_{\text{hypothèse}})$ is obtained for the pair (k, C_p) ,

f. Once all the groups with C_p set have been processed, the score s2p is obtained by averaging the scores over the pairs (k, C_p) , 515, after having processed all the C_p , there are C_p scores s2p,

2. The overall score is obtained by aggregating the scores s1p and s2p,

3. $\hat{C}_p$ is obtained by minimizing the function (s1p and s2p) which depends on the C_p tested and on the associated score, 516.

Knowing the complexity values for the platform and for the object, the method can then run the steps presented in Figure 3 in order to determine the trajectory of the object or even alert an operator in order to modify the trajectory of the platform.

The steps described in the context of azimuth angle measurements apply also with elevation angles for a trajectory in three dimensions, or other angle measurements that can be used.

The method has defined the concept of observability which is a binary quantity: when it is borne out, it is possible to estimate the trajectory; when it is not borne out, it is not possible to converge toward a single solution or a space containing this solution. This quantity is defined, for example, as follows:

$$\Omega = \begin{cases} 1 & \text{if } C_g > C_p \\ 0 & \text{if } C_g \leq C_p \end{cases}$$

Then, based on the estimation conditions:

- if the conditions are good: the trajectory is estimated via an asymptotically unbiased method known to those skilled in the art (instrumental variable IV, weighted instrumental variable WIV, bias-compensated weighted instrumental variable BCWIV or maximum likelihood ML method),
- if the conditions are bad, advice is given on elaborate manoeuvres to increase the complexity of the trajectory of the detection device, a goniometer for example.

For its part, the estimability is a gradual quantity which provides an indication as to the optimal estimation performance levels that the user can hope to have. It is possible to choose the Cramer-Rao bound (CRB) known to those skilled in the art or any other equivalent mathematical tool. It is defined from the Fisher information matrix $\mathbf{J}$ of the estimator:

$\varepsilon = \text{tr}(\mathbf{J}^{-1})$ where the operator $\text{tr}(\cdot)$ denotes the line of a matrix or the sum of the diagonal elements.

To estimate the value of the complexity of the object observed during the type 2 cross validation step, the method can implement a pseudo-linear estimator.

From the scalar vector notations for the trajectory points, a complex notation is defined:

$$p_n = [x_n, y_n]^T \rightarrow p_n^{\text{complex}} = x_n + jy_n$$

So that the vector $\mathbf{x} = [x_1, \dots, x_N]$ is written $\mathbf{x} = \Re\{\mathbf{p}^{\text{complex}} - \mathbf{G}^{\text{complex}}\}$ and $\mathbf{y} = \Im\{\mathbf{p}^{\text{complex}} - \mathbf{G}^{\text{complex}}\}$ where $\Re\{\cdot\}$ and $\Im\{\cdot\}$ respectively denote the real part and the imaginary part.

It is then possible to determine an orthogonal space on which the projection of these coordinates is zero:

$$(\mathbf{x} \ \mathbf{y}) \begin{pmatrix} -\sin(\theta_1) & 0 & \dots & 0 \\ 0 & -\sin(\theta_2) & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & -\sin(\theta_N) \\ +\cos(\theta_0) & 0 & \dots & 0 \\ 0 & +\cos(\theta_1) & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & +\cos(\theta_N) \end{pmatrix} = 0$$

$$(\mathbf{x} \ \mathbf{y}) \begin{pmatrix} -diag(\sin(\theta)) \\ +diag(\cos(\theta)) \end{pmatrix} = 0 \text{ where the operator diag denotes the square matrix}$$

including the diagonal elements under the elements of the vector as parameter.

This equation can be rewritten after application of the compressive transformation $T(\mathbf{x} \ \mathbf{y}) = (\omega_x \ \omega_y)$.

$$(\omega_x \ \omega_y) \begin{pmatrix} T & 0 \\ 0 & T \end{pmatrix} \begin{pmatrix} -diag(\sin(\theta)) \\ +diag(\cos(\theta)) \end{pmatrix} = 0$$

or even

$$(\omega_x \ \omega_y) \begin{pmatrix} -Tdiag(\sin(\theta)) \\ +Tdiag(\cos(\theta)) \end{pmatrix} = 0$$

that can be placed in the following form:

$$(\omega_x \ \omega_y) \Theta^\perp = 0.$$

This already provides a space containing the solution which is that of the core $\Theta^\perp$. This space will give indications on the solution in the case where the complexity is insufficient for the estimation. An additional information item on the speed or distance between the sensor and the object would set a space for the compatible trajectories.

In the case where the observability is assured, the pseudo-linear estimator or EPL makes it possible to perform the estimation. The EPL can be performed with any type of linear compressive transformation suggested by the form of the trajectory and the tests performed.

Furthermore, it is possible to define, fairly simply from the above equations, the corresponding Fisher information matrix:

$$\mathbf{J} = (\Theta^\perp) \text{diag}(\rho)^{-1} \Sigma \text{diag}(\rho)^{-1} (\Theta^\perp)^T$$

where:

- 5 • $\rho = |\mathbf{P} - \mathbf{G}|$ are the distances between the object and the sensor
- Σ is the covariance matrix of the measurement noise on the angles.

This matrix can obviously be calculated with all possible
10 approximations:

- Limitation of the complexity to $\min(C_p, C_g)$
- Using the estimated distance between the sensor and the object
- Estimated measurement noise covariance matrix.

15 The trajectories estimated by the method according to the invention are then transmitted to be either displayed to an operator or injected into a higher-level system (information or other system). They thus contribute to the knowledge of the radio frequency situation surrounding the carrier.

20 Without departing from the scope of the invention, the method can be applied to estimate the trajectory of an object recognizable from its signature and not equipped with any transmitter for the implementation of the invention. Any method for calculating error between values can be used. The same applies for the compressive transformations used to reduce the
25 quantity of data implemented in the calculations which will be chosen, for example, as a function of the type of trajectory. The description has used, by way of example, a pseudo-linear estimator EPL, but the method could implement any suitable type of estimator.

30 The invention offers the advantage of being used for different moving platforms equipped with a radio goniometer or a similar device. It can



be used in all types of moving platforms provided with a radio goniometer. It makes it possible to estimate the degree of complexity of the trajectory of an object automatically, whether it is a point, a straight line or a more complex movement.

CLAIMS

1 – Method for estimating a trajectory of a first object (10) by means of a moving platform (11) equipped with means (13) for measuring at least one angle
5 between the first object (10) and the platform according to a given direction comprising at least the following steps:

- determining a set of points corresponding to a trajectory of the platform for a given time interval $[t_1, \dots, t_N]$,
- acquiring a set of values of angles over the same time interval $[t_1, \dots, t_N]$,
- 10 • defining a complexity C_g of the trajectory of the platform (11) by calculating a first error existing between the points of the trajectory partitioned into a plurality of groups of points and points of the trajectory obtained by extrapolation after compression of the trajectory,
- determining, for the same time interval $[t_1, \dots, t_N]$, a complexity c_p of the
15 trajectory of the first object (10) from an estimated complexity value C_g of the trajectory of the platform and of a second error calculated between values of angles $\theta = [\theta_1, \dots, \theta_N]$ measured and partitioned into K groups and values of angles obtained by extrapolation of an estimated trajectory of the object,
- 20 • comparing the value of the complexity C_g of the platform and, if the value of the complexity of the platform is greater than the value of the complexity c_p of the object, then estimating a trajectory of the object, otherwise, transmitting a signal or an information item to adjust the trajectory of the platform.

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2 – Method according to Claim 1, characterized in that it comprises at least the following steps:

- a) estimating the complexity C_g associated with the trajectory of the platform by distributing, for a defined complexity value, the points of the trajectory randomly
30 in K groups, applying a compressive transformation and its inverse to a group of points to obtain a second group of points for each complexity,

- and extrapolating the points, then determining the error existing s_{1g} between the points defining the trajectory of the platform and the points obtained by extrapolation, reiterating these steps by working on a set of groups of points by random draw and without overlap, then defining a second error value s_{2g} ,
- 5 defining the minimum error value and the associated compressive transformation,
- b) estimating the complexity C_p of the trajectory of the moving object from an estimated complexity value of the platform, by constructing K groups of angles by random draw without repetition, for each group k , by applying a
- 10 compressive transformation in order to determine a first trajectory for the object and by extrapolating the value of the first trajectory for the time indices specific to the group k , by reconstructing the values of angles observed by the platform if the object had followed this extrapolated second trajectory, and by calculating the value of the error to obtain a first score s_{1p} , then by
- 15 reiterating these steps for a set of groups of angles obtained by a subdivision in the order of the indices of the angles and without overlap and for each chosen complexity value, in order to obtain a second score, defining the minimum value,
- c) comparing the value of the complexity C_g of the trajectory of the platform
- 20 and the value of the complexity C_p of the trajectory of the object and, if C_g is greater than c_p , then executing an algorithm for estimating the trajectory of the object, otherwise modifying the complexity of the trajectory of the platform.
- 25 3 – Method according to Claim 1, characterized in that the error values are calculated by a quadratic error calculation method.
- 4 – Method according to one of the preceding claims, characterized in that the angles are measured by goniometry or radio goniometry.

5 – Method according to one of Claims 1 to 3, characterized in that a signature of the object is used in order to determine the angles.

6 – Method according to one of Claims 1 to 5, characterized in that the object
5 is moving relative to the platform.

7 – System for estimating a trajectory of a first object (10) moving relative to
a moving platform (11) equipped with means (13) for measuring at least one
angle between the first object (10) and the platform according to a given
10 direction, characterized in that the platform (11) comprises means suitable for
executing the steps of the method according to one of Claims 1 to 5.

8 – System according to Claim 7, characterized in that the platform (11) is
equipped with a goniometer.