

Method for correcting position estimations by selecting pseudo-distance measurements

5 The invention relates to a method for correcting position estimations by selecting pseudo-distance measurements and a receiver implementing the method. It applies notably to the field of satellite navigation systems.

 Satellite positioning systems are usually designated by the
10 acronym GNSS, standing for "Global Navigation Satellite System". This type of system makes it possible to estimate the position of a terminal using an embedded navigation receiver. This receiver performs measurements on the signals that reach it, said signals being transmitted by a plurality of satellites. These measurements correspond, for example, to pseudo-distances, that is
15 to say, measurements of the distance between the satellite at the instant of transmission of the signal and the receiver at the instant of reception of the signal.

 The position estimated by the navigation receiver is not always exact. In order to take account of the lack of accuracy in the positioning, it is
20 commonplace to define a protection radius around the estimated position.

 Different types of errors may degrade the accuracy of the measurements. These errors can be classified in two categories: nominal errors and non-nominal errors.

 Nominal errors are measurement errors resulting from
25 disturbances occurring in normal operation of the system. As an example, the clock used by a transmitter embedded in a satellite has a behavior which is not totally predictable. The estimation accuracy may also be affected by the environment in the vicinity of the receiver. Other forms of nominal errors are due to the reflections of the satellite signals on the ground or on buildings in
30 the vicinity of the receiver. Also worth mentioning are the meteorological or ionospheric phenomena that may introduce a delay into the propagation of the signals to be measured.

 Non-nominal errors are the result of a system malfunction. The measurements affected by such errors are also called aberrant
35 measurements hereinafter in the description.



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In order to limit the impact of these measurement errors on the accuracy of the position estimation, means making it possible to identify such errors to eliminate them and making it possible to compute a limit on the position error according to the available measurements are usually implemented and are designated by the acronym RAIM, standing for "Receiver Autonomous Integrity Monitoring".

The current positioning appliances that include RAIM functionalities suffer from a number of problems.

A first problem is that these appliances are fully integrated, which means that it is not possible to separately choose the appliance which acquires the navigation signal and the one which computes the position of the appliance handling the integrity functions.

A second problem is that these appliances are usually based on least squares-type algorithms. This means that these appliances are destabilized by the presence of errored measurements resulting from non-nominal errors and/or an imperfect modeling of the error regardless of the amplitude of the error affecting these measurements. The solutions thus proposed are then unreliable in the face of such errors.

Robust estimation methods such as the use of the Huber algorithm make it possible to improve the estimation accuracy in the presence of aberrant measurements, but the effect of these errors is, despite everything, not inconsiderable.

One aim of the invention is notably to overcome the abovementioned drawbacks.

To this end, the subject of the invention is a method for correcting position estimations, an enhanced position $\mathbf{X}_{\text{huber}}$ being determined by application of a robust estimation algorithm using N measurements of pseudo-distances p_i corresponding to the distance measured between a navigation receiver and N satellites and an estimation $\mathbf{X}_{\text{prim}}$ of the position of said receiver made by said receiver. The method comprises at least the following steps:

- determination of normed residue values $\Delta r_{\text{huber}}^i$ from the residues $\Delta p_{\text{huber}}^i$ of pseudo-distances from the measurements p_i

- determination of Σ subsets, a subset comprising N-k normed residue values Δr_{huber}^i , k being an integer strictly greater than 1;
- selection of the subset SEO with the smallest standard deviation σ_{SEO} ;
- selection of non-aberrant measurements, a measurement being selected if the difference between the normed residues Δr_{huber}^i and the mean μ_{SGO} of the normed residues of the subset SEO is less than a predetermined threshold value T_1 ;
- determination of a corrected estimation X_{clin} of the position from the selected measurements.

According to one aspect of the invention, the robust estimation algorithm is the Huber algorithm.

The Huber algorithm is, for example, initialized by using the position X_{prim} .

In one embodiment, the residues Δp_{huber}^i are determined by using the following expression:

$$\Delta p_{huber}^i = \delta(X_{sat}^i - X_{huber})$$

in which:

- X_{sat}^i represents the position of the ith satellite, said position being for example communicated to the receiver by using a signaling channel;
- $\delta(X_{sat}^i - X_{huber})$ represents the deviation between the estimation of the difference $(X_{sat}^i - X_{huber})$ and the measured pseudo-distance p_i .

According to an advantageous embodiment of the invention, the position X_{clin} is determined by using a least squares-type method or a robust estimation method.

The normed residues Δr_{huber}^i can be determined by using the following expression:

$$\Delta r_{huber}^i = \Delta p_{huber}^i / \sigma_i$$

in which:

σ_i represents the a priori variances of the measurement errors.

According to one aspect of the invention, the number Σ of subsets corresponds to the number of combinations of (N-k) measurements out of N.

Moreover, the invention provides a step for determining N residues Δr_{clin}^i of pseudo-distances, the following expression being used:

$$\Delta r_{\text{cln}}^i = \delta (\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{cln}}) / \sigma_i$$

in which

$\delta(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{cln}})$ represents the deviation between the estimation of the difference $(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{cln}})$ and the measured pseudo-distance ρ_i .

5 The method includes, for example, a second step for selecting measurements ρ_i from the measurements already selected, said measurements being selected if the following expression is satisfied:

$$|\Delta r_{\text{cln}}^i - \Delta r_{\text{huber}}^i| < T_2$$

in which T_2 is a predetermined threshold value.

10 In one mode q implementation, a robust position estimation X_{rob} is estimated by applying the least squares method to the measurements selected during the second selection step.

A detection radius value is determined, for example, on the basis of the measurements selected during the second selection step.

15 The invention also relates to a navigation receiver implementing the method described previously.

Advantageously, the method makes it possible to optimize the choice of the hardware for acquiring the navigation signal independently of the hardware performing the RAIM processing. Furthermore, the robust RAIM method makes it possible to make the position estimation reliable while improving integrity performance in terms of detection compared to a standard RAIM.

25 Other features and advantages of the invention will become apparent from the following description given as a nonlimiting illustration, and in light of the appended drawings in which:

30 - the single figure shows a simplified diagram of the method for estimating the position of a navigation receiver by selecting pseudo-distance measurements.

The method is based on data transmitted by a primary receiver 100, that is to say a conventional navigation receiver not implementing said method. These data correspond on the one hand to the solution estimated

101 by the primary receiver and on the other hand to the pseudo-distance measurements 102 obtained by processing signals originating from N satellites. The solution estimated by the primary receiver corresponds to the estimated position of the receiver denoted $\mathbf{X}_{\text{prim}}$ and to the estimated clock
 5 offset. The N measurements 102 of pseudo-distances denoted p_i correspond to the distance measured between the receiver and the N satellites, i corresponding to the index of one satellite out of the N satellites on which measurements are performed.

If the measurements transmitted by the primary receiver are not
 10 preprocessed, they should be made to undergo a preprocessing, known per se, ridding them of propagation and measurement errors, as symbolized by the broken line rectangle 103.

A first processing 104 applied to the solutions 101 and measurements 102 mentioned previously aims to determine an enhanced
 15 position of the receiver by the use of a robust estimation method, that is to say a method that is effective in the presence of non-nominal errors. A robust method that can be employed in the context of the invention is the so-called Huber method. This method is explained in the article by X. W. Chang and Y. Guo entitled *Huber's M-estimation in relative GPS positioning: computational*
 20 *aspects*, Journal of Geodesy, 2005, vol. 79, no. 6-7, pp. 351-362. The principle of this method is to weight the measurements p_i by a function of the residue of measurements with respect to the current computation position. This computation may be initialized by using, for example, the position $\mathbf{X}_{\text{prim}}$ determined by the primary receiver. The result of this is an enhanced position
 25 denoted $\mathbf{X}_{\text{huber}}$ and a set of pseudo-distance residues. The residues are denoted $\Delta p_{\text{huber}}^i$ and are determined, for example, by using the following expression:

$$\Delta p_{\text{huber}}^i = \delta(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{huber}}) \quad (1)$$

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in which:

$\mathbf{X}_{\text{sat}}^i$ represents the position of the ith satellite, said position being, for example, communicated to the receiver by using a signaling channel;
 $\delta(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{huber}})$ represents the deviation between the estimation of the
 35 difference $(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{huber}})$ and the measured pseudo-distance p_i .

The enhanced position X_{huber} and the set of the pseudo-distance residues $\Delta p_{\text{huber}}^i$ obtained in this way are then used to detect any aberrant measurements among the N measurements p_i .

5 The detection of aberrant measurements is performed by defining, first of all, normed residues $\Delta r_{\text{huber}}^i$, then by forming subsets of said residues and by applying statistical tests to these subsets to determine whether a measurement is aberrant or not.

10 The normed residues $\Delta r_{\text{huber}}^i$ can be determined by using the following expression:

$$\Delta r_{\text{huber}}^i = \Delta p_{\text{huber}}^i / \sigma_i \quad (2)$$

15 in which σ_i represents the a priori variances of the measurement errors, an error distribution model that is based on a Gaussian law usually being used.

Subsets 105, 106 comprising $N-k$ normed residue values $\Delta r_{\text{huber}}^i$ are then formed 111, the parameter k corresponding to the maximum number of aberrant measurements to be safeguarded against.

20 The number Σ of subsets determined in this way corresponds to the number of combinations of $(N-k)$ measurements out of N , denoted $\Sigma = C[(N-k), N]$. In other words, the Σ subsets are all the combinations comprising $N-k$ residues.

25 The standard deviation of these sets is then computed. Out of these sets, a set called optimal subset and designated by the acronym SGO is determined. The SGO is the set whose standard deviation σ_{SEO} is the smallest. The mean of the normed residues belonging to the SEO is determined and denoted μ_{SGO} . The determination of the set SEO makes it possible to list the k measurements that have the greatest probability of being errored and to have a reference subset that is reputed to be reliable.

30 Two statistical tests are then applied 107, 108 so as to deny or confirm the aberrant character of the measurements.

35 A first statistical test 107 is for comparing the N deviations defined by the difference between the normed residues $\Delta r_{\text{huber}}^i$ and the mean μ_{SGO} with a threshold value T_1 . This threshold value T_1 is determined so as to guarantee objectives chosen by the designer in terms of false alarm and

detection performance. This test may be formulated, for example, by using the following expression:

$$\Delta r_{\text{huber}}^i - \mu_{\text{SEO}} < T_1 \quad (3)$$

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If the inequality (3) for the index i is satisfied, then the i th measurement ρ_i is not considered to be aberrant. In this case, it is retained to recompute a position $\mathbf{X}_{\text{cln}}$, called proper position. This proper position is preferably determined by using the least squares method, but another estimation
10 method such as, for example, a robust estimation method, may be used.

A second statistical test 108 making it possible to refine the position correction is then applied. For this, a new set of N residues Δr_{cln}^i of normed pseudo-distances is formed. The residues of this set are defined, for example, by using the following expression:

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$$\Delta r_{\text{cln}}^i = \delta(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{cln}}) / \sigma_i \quad (4)$$

in which $\delta(\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{cln}})$ represents the deviation between the estimation of the difference $\mathbf{X}_{\text{sat}}^i - \mathbf{X}_{\text{cln}}$ and the measured pseudo-distance ρ_i .

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The standard deviation σ_{cln} of this set is determined. The deviation between the residues Δr_{cln}^i and the residues $\Delta r_{\text{huber}}^i$ is determined in order to quantify the contribution of the filtering of the measurements resulting from the first test 107 to the newly estimated position $\mathbf{X}_{\text{cln}}$.

25 If this deviation is less than a threshold value T_2 , the measurements are retained. The threshold value T_2 is chosen according to the desired false alarm and detection performance levels. In other words, this test can be summarized by using the following expression:

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$$|\Delta r_{\text{cln}}^i - \Delta r_{\text{huber}}^i| < T_2 \quad (5)$$

If the inequality (5) is satisfied, then the measurement i is deemed valid, that is to say non-aberrant, and is retained.

The measurements retained following the application of the two tests are
35 used to determine 109 a so-called robust position $\mathbf{X}_{\text{rob}}$. For this, a

conventional least squares method may be used. Another type of estimation may also be used.

The estimation of the protection radii 110 can then be done by using existing methods taking into account the number of measurements retained. As an example, the radius estimation algorithms used in the context of the LS-RAIM (Least-Square RAIM) type RAIM methods and of the MHSS (Multiple Hypothesis Separate Solutions) solution separation method type may be used.

Thus, the application of the steps described previously makes it possible to obtain a corrected position solution if an error in the input measurements p_i is detected. A protection radius value is also available, which makes it possible to guarantee the position solution X_{rob} .

CLAIMS

- 1- A method for correcting position estimations, an enhanced position $\mathbf{X}_{\text{huber}}$ being determined by application of a robust estimation algorithm (104) using N measurements (102) of pseudo-distances p_i corresponding to the distance measured between a navigation receiver and N satellites and an estimation $\mathbf{X}_{\text{prim}}$ of the position of said receiver (103) made by said receiver, characterized in that it comprises at least the following steps:
- determination of normed residue values $\Delta r_{\text{huber}}^i$ from the residues $\Delta p_{\text{huber}}^i$ of pseudo-distances from the measurements p_i ;
 - determination (111) of Σ subsets (105, 106), a subset comprising N-k normed residue values $\Delta r_{\text{huber}}^i$, k being an integer strictly greater than 1;
 - selection of the subset SEO with the smallest standard deviation σ_{SEO} ;
 - selection of non-aberrant measurements (107), a measurement being selected if the difference between the normed residues $\Delta r_{\text{huber}}^i$ and the mean μ_{SGO} of the normed residues of the subset SEO is less than a predetermined threshold value T_1 ;
 - determination of a corrected estimation $\mathbf{X}_{\text{clin}}$ of the position from the selected measurements.
- 2- The method as claimed in claim 1, characterized in that the robust estimation algorithm is the Huber algorithm.
- 3- The method as claimed in claim 2, characterized in that the Huber algorithm is initialized by using the position $\mathbf{X}_{\text{prim}}$.
- 4- The method as claimed in any one of the preceding claims, characterized in that the residues $\Delta p_{\text{huber}}^i$ are determined by using the following expression:

$$\Delta p_{huber}^i = \delta(\mathbf{X}_{sat}^i - \mathbf{X}_{huber})$$

in which:

$\mathbf{X}_{sat}^i$ represents the position of the i th satellite, said position being for example communicated to the receiver by using a signaling channel;

$\delta(\mathbf{X}_{sat}^i - \mathbf{X}_{huber})$ represents the deviation between the estimation of the difference $(\mathbf{X}_{sat}^i - \mathbf{X}_{huber})$ and the measured pseudo-distance ρ_i .

5- The method as claimed in any one of the preceding claims, characterized in that the position $\mathbf{X}_{cln}$ is determined by using a least squares-type method or a robust estimation method.

6- The method as claimed in any one of the preceding claims, characterized in that the normed residues Δr_{huber}^i are determined by using the following expression:

$$\Delta r_{huber}^i = \Delta p_{huber}^i / \sigma_i$$

in which:

σ_i represents the a priori variances of the measurement errors.

7- The method as claimed in any one of the preceding claims, characterized in that the number Σ of subsets corresponds to the number of combinations of $(N-k)$ measurements out of N .

8- The method as claimed in any one of the preceding claims, characterized in that it includes a step for determining N residues Δr_{cln}^i of pseudo-distances, the following expression being used:

$$\Delta r_{cln}^i = \delta(\mathbf{X}_{sat}^i - \mathbf{X}_{cln}) / \sigma_i$$

in which

$\delta(\mathbf{X}_{sat}^i - \mathbf{X}_{cln})$ represents the deviation between the estimation of the difference $(\mathbf{X}_{sat}^i - \mathbf{X}_{cln})$ and the measured pseudo-distance ρ_i .

- 9- The method as claimed in claim 7, characterized in that it includes a second step (108) for selecting measurements p_i from the measurements already selected, said measurements being selected if the following expression is satisfied:

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$$| \Delta r_{\text{clin}}^i - \Delta r_{\text{huber}}^i | < T_2$$

in which T_2 is a predetermined threshold value.

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- 10- The method as claimed in claim 8, characterized in that a robust position estimation X_{rob} is estimated by applying the least squares method to the measurements selected during the second selection step (108).

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- 11- The method as claimed in any one of claims 9 or 10, characterized in that a detection radius value (110) is determined on the basis of the measurements selected during the second selection step (108).

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- 12- A navigation receiver, characterized in that it implements the method as claimed in any one of the preceding claims.