(19) DANMARK

(10) **DK/EP 3480622 T3**

Patent- og Varemærkestyrelsen

(12) Oversættelse af europæisk patentskrift

(51) Int.Cl.: ***G 01 S 13/00 (2006.01)*** ***G 01 S 13/48 (2006.01)*** ***G 01 S 13/524 (2006.01)*** ***G 01 S 13/87 (2006.01)*** ***G 01 S 19/14 (2010.01)*** *G 01 S 13/02 (2006.01)*

(45) Oversættelsen bekendtgjort den: **2021-08-23**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2021-05-19**

(86) Europæisk ansøgning nr.: **18200497.8**

(86) Europæisk indleveringsdag: **2018-10-15**

(87) Den europæiske ansøgnings publiceringsdag: **2019-05-08**

(30) Prioritet: **2017-11-07 FR 1701143**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

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(54) Benævnelse: **FREMGANGSMÅDE TIL DETEKERING AF MÅL VED GNSS-REFLEKTOMETRI OG TILHØRENDE SYSTEM**

(56) Fremdragne publikationer:

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UNWIN M ET AL: "Implementing GNSS-Reflectometry in Space on the TechDemoSat-1 Mission", GNSS 2014 - PROCEEDINGS OF THE 27TH INTERNATIONAL TECHNICAL MEETING OF THE SATELLITE DIVISION OF THE INSTITUTE OF NAVIGATION (ION GNSS+ 2014), THE INSTITUTE OF NAVIGATION, 8551 RIXLEW LANE SUITE 360 MANASSAS, VA 20109, USA, 12 septembre 2014 (2014-09-12), pages 1222-1235, XP056007874,
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The invention relates to a method for detecting a target by GNSS reflectometry.

The term “target” is understood to mean an element possessing reflective properties that are different from those of the surface on which it is found. These different reflective properties may be due, nonlimitingly, to a different geometry (e.g. ice peak in a flat extent of ice) or a different composition (e.g. metal structure on a body of water).

The reflective properties may be of specular or diffuse type, or any combination thereof.

GNSS reflectometry is an original and opportunistic remote sensing technique that consists in analysing the electromagnetic waves continuously emitted by the sixty satellites of GNSS positioning systems (GALILEO, GPS, GLONASS, etc.), which are captured by an antenna after reflection from the surface of the Earth. These signals interact with the reflecting surface and therefore contain information on its properties, which may be observed in the signal received after reflection. Although the feasibility and advantageousness of this method have been amply demonstrated, in particular in aeronautical fields, the implementation of this technique poses a certain number of problems in a spatial context.

The GNSS is therefore used as a radar, and receives the echo after reflection from the surface of the Earth, and deduces, by analysis of the echo, the properties of this surface.

It is an advantageous alternative to radar, at least for low-cost applications, in particular because it is not necessary to pay for the source (the emitter of the radar, with all that it costs in terms of consumption), as it is continuously available (no need to wait for the return of the satellite or of the carrier of the radar).

It is for example known that document FR2972806 A1 discloses a method of detecting and locating an object within an observation surface, the method implementing the reception, via a reception platform moving during an observation period of the observation surface, of an opportunity signal after its reflexion on the observation surface.

It is also known document UNWIN MET AL: ”Implementing GNSS- reflectometry in Space on the TechDemoSat-1 Mission”, GNSS 2014- PROCEEDINGS OF THE 27TH INTERNATIONAL TECHNICAL MEETING OF THE SATELLITE DIVISION OF THE INSTITUTE OF NAVIGATION (ION GNSS+ 2014), THE INSTITUTE OF NAVIGATION, 8551 RIXLEW LANE SUITE 360 MANASSAS, VA 201 09, USA, 12 September 2014, pages 1222-1235, XP056007874.

GNSS reflectometry has been used for a number of years, in an airborne context, for example in agriculture and the surveillance of forests.

However, the link budget is not high enough for simple implementation of GNSS reflectometry on conventional low Earth orbit (LEO) satellites, a low Earth orbit generally being considered to be lower than 2000 km.

In the present case, a target may be a ship on the ocean (small surface of specular reflection in the middle of a surface of generally diffuse reflection), a portion of a pole not covered by ice (small surface of diffuse reflection in the middle of a surface of specular, on the whole, reflection).

One aim of the invention is to overcome the aforementioned problems.

The invention proposes, according to one of its aspects, an iterative method for detecting, with at least one receiver satellite in orbit, a target possessing reflective properties that are different from those of the surface on which said target is found, by GNSS reflectometry, wherein the reflected GNSS signals are received by an active antenna of the receiver satellite comprising a plurality of antenna elements, comprising a step of determining assumed positions of the target, for which positions it is desired to detect the target, for each assumed position of the target, the following steps are carried out:

- determining a time interval in which said assumed position of the target is visible from the receiver satellite, and dividing this time interval into time segments, for each of which the following steps are carried out:

- determining the direction of arrival of the reflected GNSS signals from said assumed position of the target on the basis of the orbital position of the receiver satellite;

- determining the orbital positions of the GNSS satellites from their ephemeris data, then the directions of arrival of the direct GNSS signals of the GNSS satellites visible on a GNSS receiver of the satellite, and of the disrupting specular-reflection echo of the GNSS signals on the surface in which the target is found;

- correlating, for each visible GNSS satellite, the assumed position of the target, in the GNSS code corresponding to this GNSS satellite, and forming beams with the active antenna while maximising the gain of the active antenna in the direction of arrival of the signals from the assumed position of the target, and while minimising the gain of the active antenna in the directions of arrival of the direct signals of the GNSS satellites visible to the GNSS receiver and of the disrupting specular-reflection echo on said surface in which the target is found;

- determining the expected arrival time and the expected time variation of the arrival phase of GNSS signals potentially reflected on the target, and averaging, over the visible GNSS satellites, the correlation in the GNSS code for the arrival times and time variation in the arrival phase, on the basis of the orbital position of said receiver satellite and of its evolutions and of the orbital positions of the GNSS satellites visible from the assumed position of the target and their evolutions; and

- averaging, over the time segments, said averages of the correlation over the GNSS satellites;

- determining whether the target is present at the assumed position by comparing said average over the time segments with a reference value.

Thus, the method makes it possible to be able to use GNSS signals to locate a target.

In one implementation, the orbital position of the receiver satellite is determined on the basis of a GNSS receiver placed on said satellite.

Thus, the satellite not only has a means for determining its position, but also a capacity to collect the GNSS-satellite ephemeris data required by geometric calculations allowing reception geometries and time variations in characteristics of the received signals to be evaluated.

In one implementation, the reference value of the step of determining whether the target is present is preset.

Thus, it is possible to identify the presence of a particularly reflective (diffuse, respectively) target by observing a high (low, respectively) coherence in the signals received from this direction. This may in particular be useful in an experimental context, or at the start of satellite operation, in order to set the sensitivities of the algorithms on certain known points.

In one implementation, the reference value of the step of determining whether the target is present is adaptive.

Thus, it is possible to adapt the thresholds to the observed environment, for example to define higher detection thresholds in maritime zones with a lot of ships to identify, without confusion, only larger targets, and to return to lower thresholds to detect smaller targets, when the risk of confusion is lower.

In one embodiment, the target is a ship or boat on a body of water.

As a variant, the target is a surface not covered by ice at one of the Earth's poles.

The invention also proposes, according to another of its aspects, a system for detecting, with a satellite in orbit, a target possessing reflective properties that are different from those of the surface on which it is found, by GNSS reflectometry, said system being suitable for implementing the method such as described above.

The invention will be better understood on studying a few embodiments that are described by way of completely nonlimiting example and illustrated by the drawing in which Figure 1 schematically illustrates one implementation of the method according to one aspect of the invention.

The iterative method for detecting, with at least one receiver satellite in orbit, a target possessing reflective properties that are different from those of the surface on which said target is found, by GNSS reflectometry, wherein the reflected GNSS signals are received by an active antenna of the receiver satellite comprising a plurality of antenna elements, comprising a step E1 of assumed positions of the target, for which positions it is desired to detect the target, and, for each assumed position of the target, the following steps are carried out:

- determining E2 a time interval in which said assumed position of the target is visible from the receiver satellite, and dividing this time interval into time segments, for each of which the following steps are carried out:

- determining E3 the direction of arrival of the reflected GNSS signals from said assumed position of the target on the basis of the orbital position of the receiver satellite;

- determining E4 the orbital positions of the GNSS satellites according to their ephemeris, then the directions of arrival of the direct GNSS signals of the GNSS satellites visible to a GNSS receiver of the satellite, and of the disrupting specular-reflection echo of the GNSS signals on the surface on which the target is found;

- correlating E5, for each visible GNSS satellite, the assumed position of the target, in the GNSS code corresponding to this GNSS satellite, and forming beams with the active antenna while maximising the gain of the active antenna of the receiver satellite in the direction of arrival of the signals from the assumed position of the target, and while minimising the gain of the active antenna of the receiver satellite in the directions of arrival of the direct signals of the GNSS satellites visible to the GNSS receiver and of the disrupting specular-reflection echo from said surface on which the target is found;

- determining E6, at the receiver satellite, the expected arrival time and the expected time variation in the arrival phase of GNSS signals potentially reflected on the target, and averaging, over the visible GNSS satellites, the correlation in the GNSS code for the arrival times and time variation in the arrival phase, on the basis of the orbital position of said receiver satellite and of its evolutions and of the orbital positions of the GNSS satellites visible from the assumed position of the target and their evolutions; and

- averaging E7, over the time segments, said averages of the correlation over the GNSS satellites;

- determining E8 whether the target is present at the assumed position by comparing said average over the time segments with a reference value.

The present invention is in particular based on the use of an active multiple-beam antenna in the receiver satellite or receiver satellites, in low or LEO orbits. In the case of a plurality of satellites, it is also necessary to manage the communications between the various satellites. Use of a single receiver satellite will therefore be preferred.

The use of an active antenna in particular allows coherent recombination of signals in a determined direction, or direction of a potential target, allowing the gain in this direction to be improved in proportion to the number of antennas used for the recombination of the signals, but also signals to be cancelled out in directions that are judged to be interfering, in particular in the direction of the specular reflection of each GNSS satellite, making it possible to concentrate on the reception of non-specular echoes.

In addition, since these two elements may be implemented in a dynamic and continuous way, adapted to the relative movements of the GNSS satellites, of the LEO carrier satellite and of the targets (which are assumed to be stationary or slowly moving) on Earth, it is also possible to increase the number of constellations used, the adaptive beam formation also possibly being used to mitigate problems created by the disrupting specular-reflection echo of the GNSS signals on the surface on which the target is found, a.k.a. the “near-far” effect, and to increase the durations of (coherent and/or incoherent) integration and therefore once again increase target-detection sensitivity.

The orbital position of the receiver satellite may be determined on the basis of the GNSS receiver. An evolution in position may be calculated by a time derivative of the position.

The reference value may be preset or adaptive.

The target may be a ship on a body of water or on a surface that is not covered by ice at one of the Earth’s poles.

The principle of the invention is the application of a series of interrelated loops, pressed on the reception outputs and on the GNSS correlations/

For each position on Earth, defined by a mesh dependent on the GNSS signal of highest resolution (of largest bandwidth):

- o If it is not visible: nothing
- o If it becomes visible: start the integration
- o If it its visibility ends: decision on the presence of a target
- o If it is still visible:
- ▪ For each GNSS satellite:
- ▪ Determining the optimal beamforming allowing pointing toward the reflection, on this source, of the signal emitted by the GNSS satellite, and the removal of sea clutter and of the visible satellites liable to create a near-far effect, in an amount of N-2 satellites removed with a N number of antennas

- Determining the reception time and frequency expected for such a signal reflected on the target given the position of the target and the positions and speeds of the LEO and GNSS satellites.
- Coherently correlating the GNSS replica for this expected reflected signal after beamforming
- Carrying out an accumulation over all the GNSS satellites

A system according to the invention for detecting, with a receiver satellite in orbit, a target possessing reflective properties that are different from those of the surface on which it is found, by GNSS reflectometry, is suitable for implementing the method such as described above.

FREMGANGSMÅDE TIL DETEKERING AF MÅL VED GNSS-REFLEKTOMETRI OG TILHØRENDE SYSTEM

PATENTKRAV

1. Iterativ fremgangsmåde til detektering, ved hjælp af mindst én satellitmodtager i kredsløb, af et mål, der har refleksionsegenskaber, som adskiller sig fra de for den overflade, hvorpå den befinder sig, ved hjælp af GNSS-reflektometri, hvor de reflekterede GNSS-signaler modtages af en aktiv antenne på modtagersatelliten, der omfatter en flerhed af antenneelementer, hvilken fremgangsmåde omfatter et trin med bestemmelse (E1) af formodede positioner for målet, på hvilke målet ønskes detektere, kendetegnet ved, at der for hver formodning om målets position udføres følgende trin:

- bestemmelse (E2) af et tidsinterval, hvori målets formodede position er synlig fra modtagersatelliten, og opdeling af dette tidsinterval i tidssegmenter, hvor der for hvert foretages følgende trin:

- bestemmelse (E3) af ankomstretningen for de reflekterede GNSS-signaler, der stammer fra den formodede position for målet ud fra modtagersatellitens orbitalposition;

- bestemmelse (E4) af GNSS-satellitternes orbitalposition ud fra deres efemerider, derefter ankomstretningerne for de direkte GNSS-signaler fra GNSS-satellitterne, der er synlige for satellittens GNSS-modtager, og af GNSS-signalernes forstyrrende spejlrefleksionsekko på den overflade, hvorpå målet befinder sig;

- korrelering (E5), for hver synlig GNSS-satellit, af målets formodede position, med den GNSS-kode, der svarer til denne GNSS-satellit, og dannelse af stråler ved hjælp af modtagersatellitens aktive antenne ved maksimering af den aktive antennes forstærkning i ankomstretningen for signalerne, der stammer fra målets formodede position, og ved minimering af den aktive antennes forstærkning i ankomstretningerne for de direkte signaler fra GNSS-satellitterne, der er synlige på GNSS-modtageren, og af det forstyrrende spejlrefleksionsekko på den overflade, hvorpå målet befinder sig;

- bestemmelse (E6) af det forventede ankomsttidspunkt og ankomstfasens forventede tidsvariation for de eventuelt reflekterede GNSS-signaler på målet, og beregning af gennemsnittet, over de synlige GNSS-satellitter, af korreleringen på GNSS-koden for ankomsttidspunkterne og ankomstfasens tidsvariation, ud fra modtagersatellitens orbitalposition og dens variationer og de synlige GNSS-satellitters orbitalpositioner for målets formodede position og deres variationer; og

- beregning af gennemsnittet (E7), over tidssegmenterne, af korelleringsgennemsnittene for GNSS-satellitterne;

- bestemmelse (E8) af, om målet er til stede ved den formodede position ved sammenligning af gennemsnittet af tidssegmenterne med en referenceværdi.

2. Fremgangsmåde ifølge krav 1, hvor modtagersatellitens orbitalposition bestemmes ud fra en GNSS-modtager placeret på satellitten.

3. Fremgangsmåde ifølge et af de foregående krav, hvor referenceværdien for trinnet med bestemmelse (E8) af målets tilstedeværelse er forhåndsbestemt.

4. Fremgangsmåde ifølge et af kravene 1 til 2, hvor referenceværdien for trinnet med bestemmelse (E8) af målets tilstedeværelse er adaptativ.

5. Fremgangsmåde ifølge et af de foregående krav, hvor målet er et skib på en vandflade.

6. Fremgangsmåde ifølge et af kravene 1 til 5, hvor målet er en overflade, der ikke er dækket af is, på én af jordens poler.

7. Detekteringssystem ved hjælp af satellit i kredsløb af et mål, der har refleksionsegenskaber, der adskiller sig fra de for den overflade, hvorpå den befinder sig, ved hjælp af GNSS-reflektometri, der er tilpasset til at udføre fremgangsmåden ifølge et af de foregående krav.

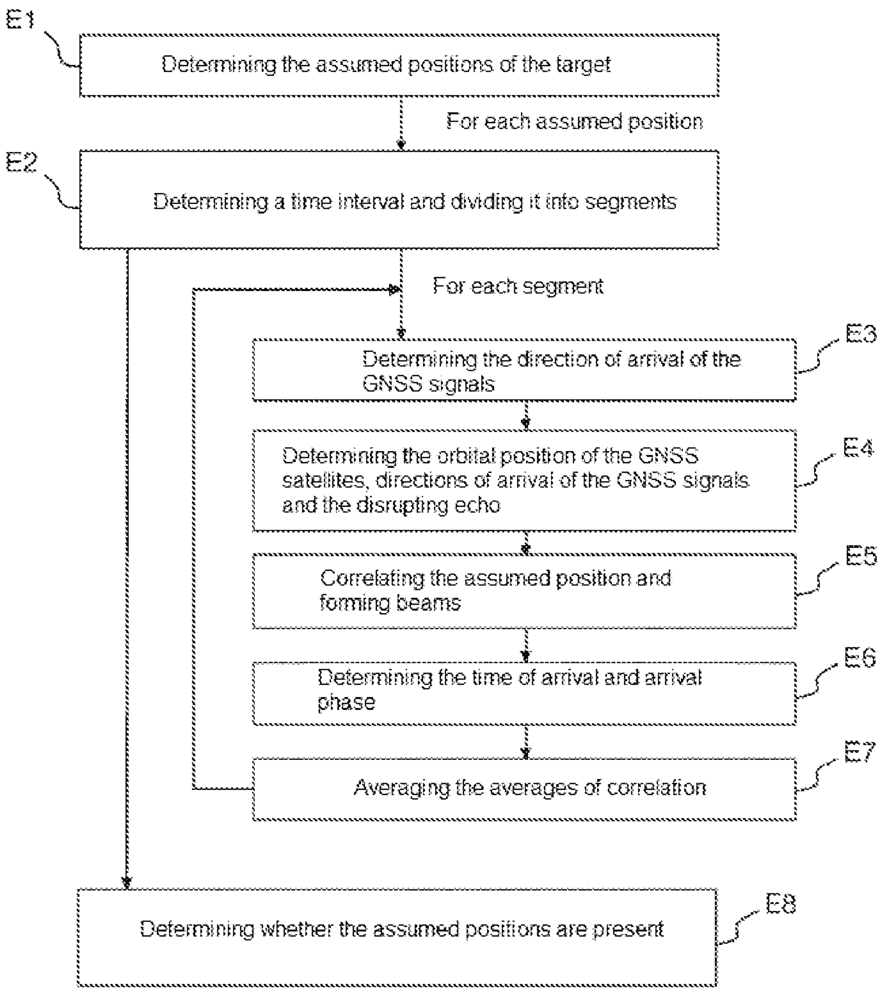
E1
Determining the assumed positions of the target
For each assumed position
E2
Determining a time interval and dividing it into segments
For each segment
E3
Determining the direction of arrival of the GNSS signals
E4
Determining the orbital position of the GNSS satellites, directions of arrival of the GNSS signals and the disrupting echo
E5
Correlating the assumed position and forming beams
E6
Determining the time of arrival and arrival phase
E7
Averaging the averages of correlation
E8
Determining whether the assumed positions are present

FIG.1