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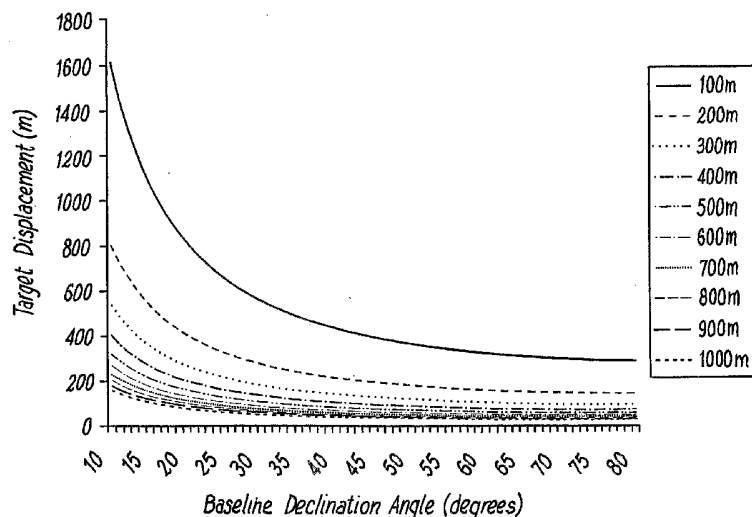
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(54) Title: RADAR POSITION AND MOVEMENT MEASUREMENT FOR GEOPHYSICAL MONITORING



(57) Abstract: InSAR monitoring of geophysical features is known but previously limited by the need to use a high resolution digital map for reference correction for phase ambiguities in the response interferogram. By estimating a determinant target position in the interferogram response using a low resolution map or geophysical feature referencing in the radar response and utilizing the position/velocity of the transmitter/receiver source, an iterative application of proposed phase ambiguity values are tried in InSAR equations for best correlation with the estimate for determinant target position. The best fit correlation is used as the operative phase ambiguity value for subsequent InSAR procedures and the target position corrected to a true position utilising the operative phase ambiguity value.

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Radar Position and Movement Measurement for Geophysical Monitoring

The present invention relates to radar position and movement measurement for geophysical monitoring and more particularly to such monitoring without high resolution digital mapping.

Synthetic aperture radar (SAR) interferometry (InSAR) is, and continues to be, a technique of great interest in geophysical remote sensing. Over the last 10-15 years, InSAR has proved itself to be a major tool in the monitoring of land deformation at centimetric accuracies. Such monitoring is utilised with respect to earthquakes, volcanoes, ice sheets, landslides and terrain subsidence.

The processes and techniques of InSAR are relatively well-known and used for monitoring geophysical activity (Rosen et al, Synthetic Aperture Radar Interferometry – Proceedings of IEEE, Vol. 88 No. 3 March 2000). In short, reflected radar signals are compared using interferometric techniques to accurately map and measures geophysical activity.

The determination of such precise motion requires the analysis of the phase part of the radar signal. In interferometric SAR, the receiver is also the transmitter, meaning that the phase is related to the two-way delay, complicated further by the scattering of the radar signal at the target, that is to say the geophysical feature map. If the scattering mechanism is unchanged from a

different receiver position, the signals are correlated and the difference in carrier phase between the two positions can be calculated.

The resulting phase difference can only be determined within a certain range of accuracy leaving a problem in that an ambiguity remains. The ambiguity means that the phase difference cannot give the geometric information required to locate target deformations. To cope with this, existing processes need extensive, accurate ground control, such as an accurate digital topographic map. Such information may not be readily available off the-shelf - even in the developed world - and so this limits the geographic extent of the applications and the speed by which information may be gathered. Gathering of additional data also has cost implications.

Accurate ground control in terms of target position is also required to provide cross-check correlation between the response interferogram and the true interferogram distorted due to varying conditions. If an accurate determination of at least one target position is known from the accurate ground map it will be understood that the interferogram for that target position can be 'tested' against the accurate position and divergence determined as the phase ambiguity for that position and associated targets about the 'tested' target. A number of known relationships such as the InSAR equation, the Range equation and the Doppler equation are used to test the detected response interferogram solution with the accurate target position taken from high resolution mapping.

A solution to the phase ambiguity problem without a requirement for accurate ground control would be advantageous.

The invention is a process for radar measurements of the position of reflecting bodies which, from a single interferometric phase measurement, identifies the integer phase ambiguity. The phase ambiguity is identified through the following steps:

- (a) For any target position on an interferogram, the respective satellite positions and velocities are calculated.
- (b) A coarse estimate of the true three-dimensional target position is determined. The required coarseness of the estimate depends on the geometric properties of the interferogram. The estimate may be derived, as appropriate, through third party data, through georeferencing of the radar imagery or from a neighbouring resolution cell whose phase ambiguity has already been identified.
- (c) The true three-dimensional target location is calculated many times, each time using different estimated values (integers) of the phase ambiguity. Each time it is calculated, its proximity to the coarse estimated target location is noted.

- (d) The phase ambiguity that gives a location closest to the coarse estimate is selected as the true phase ambiguity value and the corresponding location is the best estimate of location for the target.

Thus, the phase ambiguity may be determined for any interferometric phase element using a single, coarse ground control point.

A benefit is that, once the above process is applied to a single point within a coherent area, the phase ambiguity may be determined for all neighbouring resolution cells within a continuous, coherent region within an interferogram without repetitive application of the above process. The solution is to "grow" the phase ambiguity from a single "seed point", the point where the above, rigorous process (and for which there is ground control) has been applied. This is achieved through the following steps:

- i) For the "seed point" within the coherent region, process according to process 1.
- ii) The phase for all other points in the coherent region is then related to the seed point by the process of Phase Unwrapping, of which there are several existing methods. This entails analyzing the evolution of the Wrapped (undetermined phase ambiguity) phase over the image to determine the relative ambiguity to that of the seed point.

- iii) Differencing the wrapped and unwrapped phases gives the relative phase ambiguity for each resolution cell. The phase ambiguity of the seed point is then added to the relative values to give the true phase ambiguity values.
- iv) The phase ambiguity values are then used to derive the location of the corresponding points within the coherent region.

Thus, only a single, coarse control point is required to enable the solution of the phase ambiguity problem for a connected, coherent area.

If there is a temporal sequence of targets or connected, coherent areas for which the phase ambiguity has been derived, a further benefit is that its motion in time may be detected - this is called Differential InSAR. The precision is limited only by the accuracy of the phase measurement itself and, therefore, may give accuracies of better than 1mm, depending on the radar system configuration and wavelength.

Thus, only a single, coarse control point is required to enable the determination of motion in a connected, coherent area or for a single target.

The process is generally utilised in differential InSAR monitoring of geophysical features.

The invention is also defined in claim 1 outlined below.

Preferred features of the present invention are outlined in the dependent claims. In particular the present invention also includes a digital map and arrangement configured to operate in accordance with the present invention.

The invention encompasses three processes that are described in more detail below.

Embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 provides a graphical representation of target displacement against declination values as an indication of one source so phase ambiguity.

Geophysical monitoring is required for a number of environmental as well as academic research reasons. For example, it may be desirable to monitor land subsidence or wave motions over a time period. InSAR is useful for this type of monitoring and utilizes comparison of interferogram responses from the subject target area. However, for such comparison, accurate or more importantly consistent determinations of target position relative to the transmitter/receiver as well as of phase ambiguity are required. In such circumstances, previously a cell or pixel from the interferogram was accurately calibrated relative to an accurate

digital map for resolution of phase ambiguities as well as positional referencing. Unfortunately, such high accuracy digital maps may not be available particularly

in remote locations or for planetary monitoring. It will also be understood that areas that are subject to severe geophysical movements will therefore require regular updating of the high resolution digital map to be utilized in this way. This will at the very least be inconvenient.

A number of different processes in accordance with the present invention are outlined below. These processes essentially utilize an iterative approach to resolution of phase ambiguities and true target position adjustment. By first determining source, that is to say transceiver position, for the response interferogram a coarse or crude estimated position for target position can be made. In such circumstances, using the known InSAR equation, range equation and Doppler equations along with other relationships a best fit solution can be found for phase ambiguity. Once the best fit solution for phase ambiguity is found this is established as the 'true' or operative value on a best probability basis and used subsequently for correlation shift of the detected interferogram response to the set true target position by calculation from the now set operative value of the phase ambiguity.

PROCESS 1 : PHASE AMBIGUITY DETERMINATION FOR A SINGLE TARGET

The process comprises the projection of one or two SAR radar signals at a target or target area followed by the capture of the reflected radar signal(s) from the target or target area using two antennae at two different positions. The reflected signals are converted into electrical signals which are then processed in parallel using a computational device that calculates the difference in carrier phase between the signals. The resulting array of phase differences is called an interferogram. There are several ways of creating an interferogram from SAR signal data (see, for example, Rosen et al, Proceedings of the IEEE, page 333ff Vol. 8 No. 3 March 2000). The process described below consists of an algorithm or algorithms implemented on a computational device which performs mathematical operations on a single phase component (phase difference measure) of an interferogram as detailed below. The output signal from the computational device reveals information from which the position of a single target can be determined.

The position of a target in a single interferogram is derived through the solution of three equations: the InSAR equation, the Range equation and the Doppler equation. For any single InSAR result, there are actually two sets of equations, each relating to two different transceiver positions in orbit (called P1 and P2) but, because of the short baseline (orbit separation) only three can be used at anyone time. Without loss of generality, we will consider the equations relating to P1 only. They are:

$$f_{D1} = -\frac{2}{\lambda|\rho_T - \rho_{P1}|}(\rho_T - \rho_{P1}) \cdot \mathbf{v}_{P1} \quad (1)$$

$$\rho_1 = |\rho_T - \rho_{P1}| \quad (2)$$

$$\frac{\lambda\phi}{4\pi} + \frac{\lambda}{2} \Delta n^2 + \delta e = \frac{|\rho_T - \rho_{P1}|^2 - |\rho_T - \rho_{P2}|^2 + B^2}{2|\rho_T - \rho_{P1}|} \quad (3)$$

ρ_T = target position (unknown)

ρ_{P1} = sensor position at P1

ρ_{P2} = sensor position at P2

v_{P1} = sensor position at P1

ρ_1 = distance between target and P1 (unknown)

f_{D1} = target doppler frequency from P1

λ = radar wavelength

ϕ = interferometric phase

Δn^{12} = integer phase ambiguity (unknown)

B = baseline (distance between P1 and P2)

δe = far-field correction (unknown), given by:

$$\delta e = \frac{B^2 - (\rho_1 - \rho_2)^2}{2\rho_1}$$

where:

ρ_2 = distance between target and P2.

Note that the form of equation (3) above is appropriate to two-pass systems. Single-pass dual-antenna systems may operate slightly differently but this equation remains the same, with the exception that first two terms on the right hand side are multiplied by a factor of 2.

The purpose of this method is to determine the integer phase ambiguity Δn^{12} . The method is given below:

- Consider that there is a coarse estimate of ρ_T . The worst-case accuracy required for this is known. Values for the ERS-I satellite are illustrated in figure 1. Coarse values of ρ_1 , ρ_2 and δe are then determined.
- Using different integer values of Δn^{12} , the range of which are determined by the coarse target position and its accuracy, different values of the true target position, ρ_T , are estimated through solution of equations 1 to 3.
- Each time ρ_T is estimated, its proximity to the coarse target position is calculated.
- The value of Δn^{12} that gives the value of ρ_T with closest proximity to the coarse target location is the true value of the phase ambiguity.
- Now that the phase ambiguity is known, ρ_1 , ρ_2 and δe can be precisely determined and the true target position estimated.

PROCESS 2: PHASE AMBIGUITY DETERMINATION FOR A CONNECTED, COHERENT REGION

The start point for the process described here is an interferogram, as described in process 1 above. This second process consists of an algorithm or algorithms implemented on a computational device which performs mathematical

operations on a continuous area in an interferogram for which the phase noise is low enough (coherent) to enable it to be determined. The output signal from the computational device reveals information from which the position of a group of connected targets can be determined.

Consider that the phase ambiguity has been determined for a single point (referred to here as the "seed point") within a wrapped, unflattened interferogram (map of interferometric phase). The process for determination of the phase ambiguity for all other points within a region connected to the seed point is as follows:

- Unwrap the phase with respect to the seed point. This basically identifies the phase ambiguities relative to the seed point. There are many ways of doing this (see, for example, Radar Interferometry: Data Interpretation and Error Analysis (Kluwer Academic Publishers, The Netherlands. Ramon F. Hanssen, 2001 – ISBN 0-7923-6945-9).
- Subtract the unwrapped phase from the wrapped phase, divide the values by 2π and round to the nearest integer values. This gives the relative phase ambiguity to the seed point.

- Add on the phase ambiguity of the seed point to the relative phase ambiguity. The result will be the true phase ambiguity of all points within the connected, coherent area.

This process will produce a map of phase ambiguities in a connected, coherent region using only a single control point. Thus, it is possible by differential InSAR to provide a land motion estimation through considering the divergency or convergency of target positions determined by using the map of phase ambiguities at those targets derived by consideration of the single control point.

PROCESS 3: PHASE DEVIATION DETERMINATION FOR A POINT WITH KNOWN PHASE AMBIGUITY

Consider that a target appears in a series of interferograms and that the corresponding integer phase ambiguity has been calculated in each case. For any two interferograms, the phase deviation Φ may be determined by:

$$\Phi = \frac{1}{B_{12}} \left(\phi_{12} + 2\pi\Delta n^{12} + \frac{4\pi}{\lambda} \delta e_{12} \right) - \frac{1}{B_{34}} \left(\phi_{34} + 2\pi\Delta n^{34} + \frac{4\pi}{\lambda} \delta e_{34} \right) - \frac{8\pi \sin \frac{1}{2}\gamma}{\lambda} \sin \left(\beta_{12} + \frac{1}{2}\gamma \right)$$

where γ is an angle relating to the particular orbit geometry (assumed known) and β_{12} is the baseline declination angle for the earliest pair, given by:

$$B_{12} \cos \beta_{12} = \frac{\lambda \phi_{12}}{4\pi} + \frac{\lambda}{2} \Delta n^{12} + \delta e_{12}$$

For three-pass interferometry, γ is simply the angle between the two orbital baselines; for four-pass, γ is still an angular difference but is related to four different orbital baselines.

Normally, when there has been no topographic change, the phase deviation is zero. In the case where there has been change, Φ can be related to line-of-sight displacement $\delta\rho$ by:

$$\delta\rho = -\frac{\lambda B_{34} \Phi}{4\pi}$$

assuming the displacement occurs in the (3,4) interferometric pair.

This process will, therefore, allow the calculation of phase deviation from a single point for which the interferometric phases and ambiguities are known. Therefore, since it is possible to calculate those values in a connected, coherent region using a single, coarse control point only (see Process 2), it is possible to

perform differential interferometry with only sparse, coarse ground control.

An unflattened interferogram is hard to interpret so most visual interpretation for ground control will be done with respect to the two amplitude/intensity images and a map of the correlation coefficient (the coherence image). The actual response will be distorted by phase ambiguities and so must be corrected for accurate monitoring to be performed. Visual identification of targets is different and so it is preferred to use GPS positions that can be located on the interferogram by modelling the imaging process.

By the present invention a target position is chosen as a determinant target for determination of the phase ambiguity. The choice of position will normally be taken with regard to the capabilities of the operational equipment and possibly proximity to specific features which it is desired to monitor. It is normal for the interferogram to be divided into a number of cells or pixels and the target will generally be consistent with one of those cells or pixels.

The position of the interrogating radar source as a transmitter/receiver will be determined. The transmitter/ receiver will normally be located in a satellite, which may be geostationary or orbiting, or in an aircraft. In either event, the position of the transmitter/receiver will be resolved for position, and velocity of the source in moving, relative to the determinant target reference features. Thus, a crude or coarse determination can then be made as to the positional location of

the determinant target using known reference features in the interferogram e.g. a relatively stable massive object or overlay of low resolution digital mapping such as GPS satellite positioning or through georeferencing of the radar imagery or by extrapolation from a neighbouring resolution cell whose phase ambiguity has already been identified. In any event, the coarse positioning of the determinant target will only be resolved to a low degree of resolution which is generally worse than fifty metres.

By the above it will be understood that estimates or crude values are provided for all parameters of the InSAR resolving equations apart from the phase ambiguity. Thus, by an iterative process of trial and substitution of proposed values for the phase ambiguity or factors thereof into these InSAR resolving equations the best fit or match to the coarse estimate of target position is made. The increments in the trial range for the proposed values of the phase ambiguity will depend upon the level of accuracy required and available processing time etc.

Once the best fit or match value for the phase ambiguity has been determined that value is then set for the monitoring period as the operative phase ambiguity value. Clearly, there will normally be a deviation from the estimated determinant target position and the target position determined by use of the operative phase ambiguity value. This is equivalent to the closeness of the best fit/match procedure previously described and so is potentially a product of the

incremental scaling used in that process. Nevertheless, for consistency the estimated determinant target position will be 'corrected' or aligned with the chosen operative phase ambiguity value as the true determinant target position for subsequent procedures and calculations.

The operative phase ambiguity value for the determinant target cell may be extrapolated to adjacent target cells as the operative value for those cells as well without further processing. Alternatively, neighbouring cells may be grouped or nested so that the method in accordance with the present invention could be independently performed upon each neighbouring cell and the operative values averaged or otherwise associated to provide a potentially better resolved operative value for the whole group.

By the present invention the positional location of the determinant target is relatively accurately resolved. Thus, if a number of such determinant target positions are resolved by the present method or by seed projection from a single determinant target position it will be understood that a relatively accurate digital topographical map may be formed between those target positions. Use of extra ground control is useful to determine other sources of error, such as atmospheric delay or orbital errors. This digital map may be used for subsequent InSAR monitoring. Furthermore, when more processing time is available the quality in terms of positional accuracy may be improved by resolution of additional determinant target positions by the present method.

By utilizing the present invention more convenient use of InSAR is provided. Examples of some of these practical applications are given below.

The benefits of all of the processes above are that more accurate 3-dimensional positioning and position changes are achieved with less ground control and that the process may be automated and improved to give a target's position in real-time and near real-time. The processes may be implemented on the ground or in the sensor itself. They may be applied to any single or dual antenna radar system employed in space, in subspace, in the air, on the land, underground, on or under water using a fixed or portable sensor on a manned or un-manned vehicle. Since radars have been employed to map the surfaces of other planets and natural satellites, the processes are also able to be employed for extra-terrestrial exploration.

The reduction in the requirement for ground control implies that any current or future mission using InSAR for mapping and monitoring does not require to build up an extensive archive of accurate ground control to support applications. This reduces cost, risk and also means that the mapping and monitoring can take place over remote areas where little or no reliable ground control is available. It also improves the capability of a mission to react quickly to critical or sudden, cataclysmic events.

Process 1 may be used to determine the 3-dimension allocation of an individual man-made or natural feature or target occurring on land, ice or as an individual target on a water surface. For example, it may be used to determine the position of a vegetated or geological feature, a glacier, a building, an oil rig or a land, air or waterbased vehicle. This is achieved through the processing of a single interferogram using only a single coarse estimate of the target's position as input. Existing methods do not work through the analysis of single targets but need a large number of targets, with accurate ground control, to achieve the same accuracy. Also, under existing methods, the targets also need to be connected - existing methods cannot process individual targets isolated in incoherent regions, such as ships in the sea - and require much manual intervention. This process eliminates those requirements.

Processes 1 & 2 allow the determination of 3-d positions (topography) for a connected, coherent area in a single SAR interferogram using only a single coarse control point. This allows the derivation of a digital surface model (DSM), which is an array of heights in some geodetic coordinate system, the heights relating to the surface imaged by the SAR. Other products such as contour, slope and drainage maps may also be derived. Existing methods require much more ground control, at a greater accuracy, to achieve the same precision, with the implication being that this method is cheaper, faster and less labour intensive. Topography may be derived over a variety of mountainous and flat topography, over land cover types including agriculture, forestry, savannah, grassland,

wetlands, deserts, bare rock, natural and artificial environments, urban, sub-urban, infrastructure, industrial, airports and areas covered in snow and ice. In certain circumstances, the technique may also be used over water surfaces, including rivers, lakes and the ocean.

Processes 1, 2 & 3 allow the determination of target motion or change. The change is determined through a process that requires the analysis of two or more SAR interferograms of the same area. The analysis may be of individual targets within the interferograms (as defined above) or of coherent, connected regions of topography (see above). Existing methods require much more ground control, at a greater accuracy, to achieve the same precision, with the implication being that this method is cheaper, faster and less labour intensive. The main applications of this process are for the determination of land deformation due to man-made and natural effects (mining, tidal pressure, tectonic motion etc.), cataclysmic events, such as earthquakes and landslides, volcanic activity, the movement of ice sheets and glaciers and the movement of individual targets (buildings, land-, sea- and air-based vehicles, rigs and platforms etc.). The monitoring of these phenomena is important for scientific modelling but also many of these applications have disastrous consequences for the environment and for human life. For example, the analysis of the magnitude and extent of subsidence due to mining activity is important for planning purposes; earthquakes and volcanoes are potentially life-threatening and this technique can help improve models and map the extent of any catastrophe in near real-time,

thus helping any aid agency to plan rescue operations.

Whilst endeavouring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

Claims

1. A method for resolving an integer phase ambiguity from interferogram phase measurements, the method taking an interferogram image from an emitter/receiver source, the method comprising:-
 - a) Choosing a target position in the interferogram image provided by operation of the source as a determinant target;
 - b) For the determinant target determining positions for the source, and if necessary relative velocities for that source, relative to the determinant target in the interferogram
 - c) Determining for the determinant target a coarse estimate as to its three dimensional position;
 - d) Determining an operative phase ambiguity value by utilizing the source positions, and if necessary the velocities for that source, by iterative application of proposed values for the phase ambiguity in a possible range to resolve determinant target position using known derivation relationships and noting the proximity to the coarse estimate for determinant target position for each proposed value of the phase ambiguity in order to determine the proposed value of the phase ambiguity which most closely correlates with the coarse estimate of determinant target position and defining that proposed value as the operative phase ambiguity value; and,

- e) Assigning the determinant target position given by the operative phase ambiguity value as the true determinant target position for subsequent procedures for interferometric analysis of the interferogram image along with consistent use of the operative phase ambiguity value.
2. A method as claimed in claim 1 wherein the coarse estimate for determinant target position is determined by crude overlay and/or reference comparison to known reference features in the interferogram.
 3. A method as claimed in claim 1 wherein the coarse estimate for determinant target position is determined by extrapolation from other coherent overlapping or adjacent or juxtaposed target positions within the interferogram.
 4. A method as claimed in any of claims 1, 2 or 3 wherein the coarse estimate for determinant target position utilizes reference to a range of reference criteria such as a low resolution digital map and/or georeferencing of radar imagery and/or from neighbouring target resolution whose phase ambiguity has already been determined.
 5. A method as claimed in any preceding claim wherein the source is mounted in a satellite or airborne vehicle.

6. A method as claimed in any preceding claim wherein a land motion estimation is provided by considering the divergence or convergence of target positions where each target position is determined using a map of phase ambiguities produced by differentiation and consideration from the operative phase ambiguity.
7. A method for resolving an integer phase ambiguity from interferogram phase measurements substantially as hereinbefore described with reference to the accompanying drawings.
8. A method as claimed in any preceding claim wherein the method is utilised or part of a differential InSAR monitoring procedure for geophysical features.
9. A digital map of a geophysical zone comprising a plurality of target positions resolved by a method defined in any preceding claim.
10. A geophysical feature monitoring arrangement comprising a transmitter/receiver source for determining an interferogram response from a target area and a processor to determine phase ambiguity and/or true target correction for the interferogram response, the processor operating in accordance with a method as claimed in any of claims 1 to 8.

11. A process for radar measurements of the position of reflecting bodies which, from a single interferometric phase measurement, identifies the integer phase ambiguity. The phase ambiguity is identified through the following steps:

- (a) For any target position on an interferogram, the respective satellite positions and velocities are calculated.
- (b) A coarse estimate of the true three-dimensional target position is determined. The required coarseness of the estimate depends on the geometric properties of the interferogram. The estimate may be derived, as appropriate, through third party data, through georeferencing of the radar imagery or from a neighbouring resolution cell whose phase ambiguity has already been identified.
- (c) The true three-dimensional target location is calculated many times, each time using different estimated values (integers) of the phase ambiguity. Each time it is calculated, its proximity to the coarse estimated target location is noted.
- (d) The phase ambiguity that gives a location closest to the coarse estimate is selected as the true phase ambiguity value and the corresponding location is the best estimate of location for the target.

12. A process as claimed in claim 11 wherein neighbour phase ambiguity value may be determined for all neighbouring resolution cells within a continuous, coherent region within an interferogram without repetitive application of the above process.

13. A process as claimed in claim 12 wherein the neighbour phase ambiguity value is extrapolated from a base phase ambiguity value determined in accordance with claim 11 by a process of steps as follows:

- i) Determine the base ambiguity value within the coherent region by the process according to claim 11.
- ii) The phase for all other points in the coherent region is then related to the base ambiguity value by the process of Phase Unwrapping and analyzing the evolution of the Wrapped (undetermined phase ambiguity) phase over the image to determine the relative phase ambiguity value to that of the base ambiguity value.
- iii) Differencing the wrapped and unwrapped phases gives the relative phase ambiguity for each resolution cell whereby the base phase ambiguity value is then added to the relative phase ambiguity value to give the true phase ambiguity values for each resolution cell.

- iv) All phase ambiguity values are then used to derive the location of the corresponding target points within the coherent region.

14. A process for radar measurement of the position of reflecting bodies substantially as hereinbefore described with reference to the accompanying drawings.

15. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.

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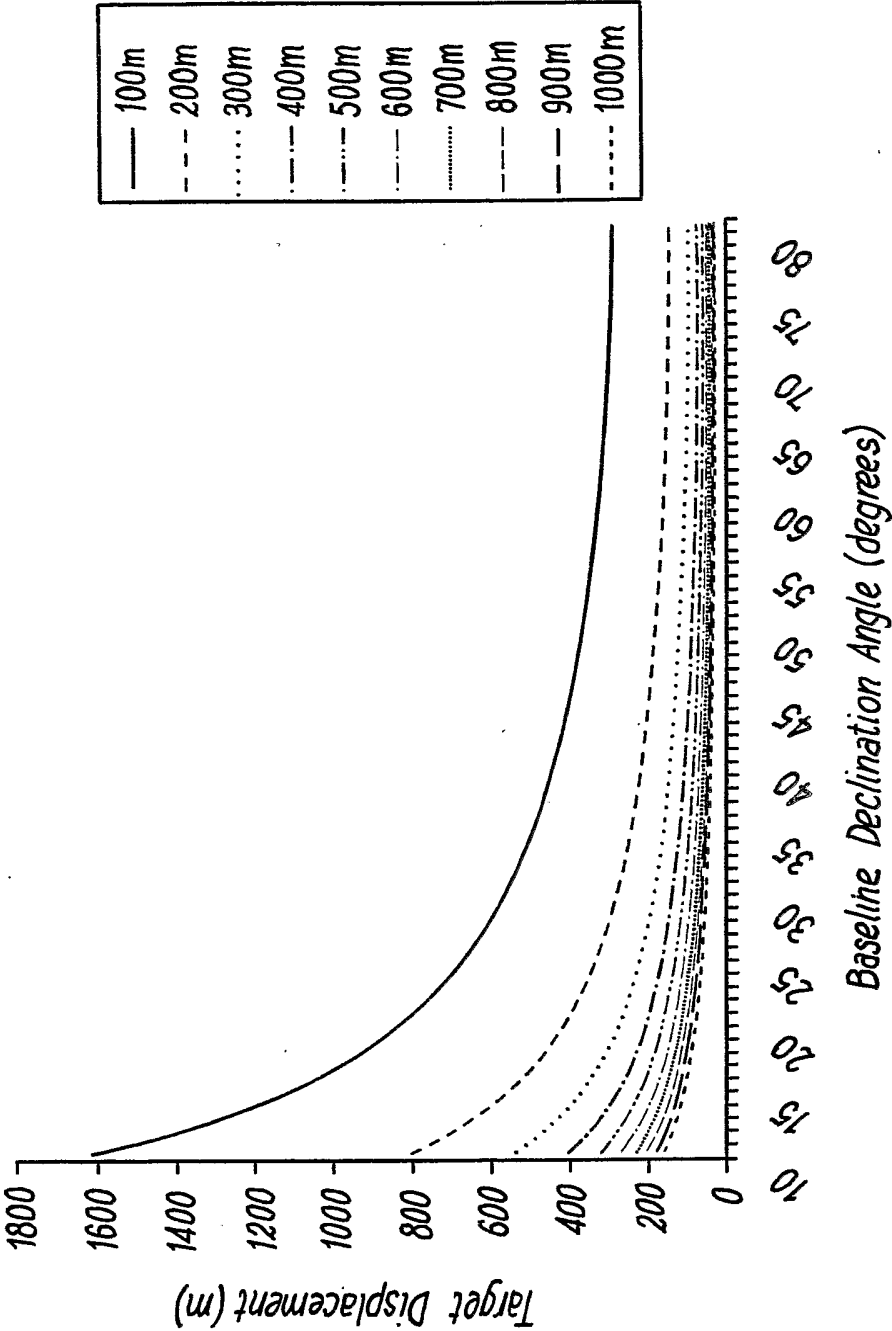


Fig. 1

INTERNATIONAL SEARCH REPORT

International Application No
 /GB2004/003246

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01S13/95

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 103 786 A (EASTMAN KODAK CO) 30 May 2001 (2001-05-30)	1-4
Y	abstract; figure 6 paragraphs '0001! - '0009!	5,6,8-13
Y	EP 0 470 816 A (IND TECHNOLOGY INST) 12 February 1992 (1992-02-12) column 5, line 21 - column 6, line 34; figures 1-4	5,6,8-13
X	US 4 975 704 A (GABRIEL ANDREW K ET AL) 4 December 1990 (1990-12-04) abstract page 5, lines 44-47 page 6, lines 4-11	1-4

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

G document member of the same patent family

Date of the actual completion of the international search

7 October 2004

Date of mailing of the international search report

15/10/2004

Name and mailing address of the ISA

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Authorized officer

Schmeitz, C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2004/003246

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International Application No. PCT/GB2004 /003246

FURTHER INFORMATION CONTINUED FROM PCT/SA/ 210

Continuation of Box II.2

Scope of claims not clear.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.5), should the problems which led to the Article 17(2) declaration be overcome.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No
/GB2004/003246

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