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**Method and device for determining correction parameters**

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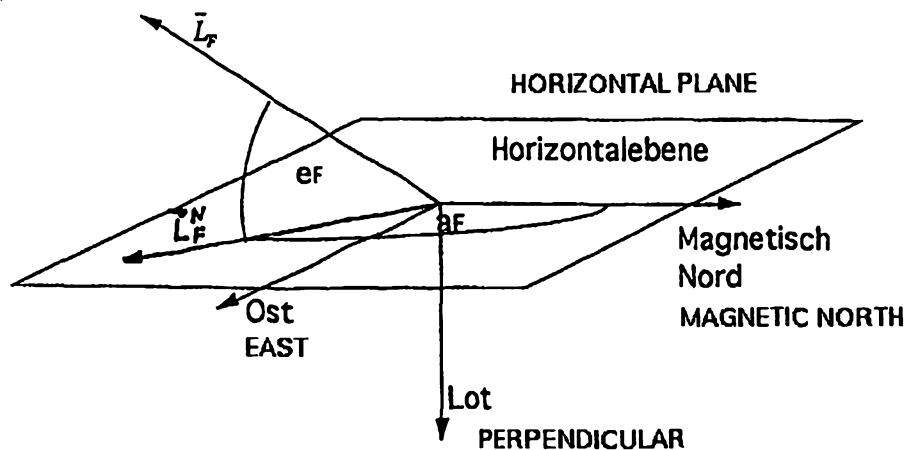
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<p>(21) Internationales Aktenzeichen: PCT/EP98/00627                  (22) Internationales Anmeldedatum: 5. Februar 1998 (05.02.98)                  (30) Prioritätsdaten:                  197 04 853.6 10. Februar 1997 (10.02.97) DE                  (71) Anmelder (für alle Bestimmungsstaaten ausser US): LEICA                  AG [CH/CH]; Postfach, CH-9435 Heerbrugg (CH).  <b>ECOSYSTEMS</b>                  (72) Erfinder; und                  (75) Erfinder/Anmelder (nur für US): GNEPF, Silvio [CH/CH];                  Weedstrasse 6, CH-9435 Heerbrugg (CH). NACHBAUR,                  Peter [AT/AT]; Münzersiedlung 3, A-6807 Feldkirch (AT).                  DITTRICH, Frank [DE/CH]; Erlenstrasse 9a, CH-9445                  Rebstein (CH).</p>	<p>(81) Bestimmungsstaaten: AU, CA, CN, JP, KR, NO, US,                  europäisches Patent (AT, BE, CH, DE, DK, ES, FI, FR,                  GB, GR, IE, IT, LU, MC, NL, PT, SE).                  Veröffentlicht                  Mit internationalem Recherchenbericht.                  Vor Ablauf der für Änderungen der Ansprüche zugelassenen                  Frist. Veröffentlichung wird wiederholt falls Änderungen                  eingetrag.  </p>	

(54) Title: METHOD AND DEVICE FOR DETERMINING CORRECTION PARAMETERS

(54) Bezeichnung: VERFAHREN ZUM BESTIMMEN VON KORREKTURPARAMETERN

(57) Abstract

The invention relates to a method for determining correction parameters for the measured values of a magnetic compass, which is built into a land craft for navigation purposes, and gives the azimuth  $a$  of the direction of motion of the vehicle; of a gradiometer giving the elevation  $e$  of the direction of motion of the vehicle in relation to the horizon; and of an odometer, giving the distance  $s$  travelled. In this method, two visually navigated test drives are



carried out in different directions between known point of departure and arrival. The measured values ( $a$ ,  $e$ ,  $s$ ) are replaced by corrected values ( $a'$ ,  $e'$ ,  $s'$ ) in accordance with the following:  $a' = a + A + B \cdot \sin a + C \cdot \cos a$ ;  $e' = e - A_2$ ;  $S' = \rho$ . The correction parameters are determined by performing a vectorial comparison of the known direction and distance values ( $a'$ ,  $e'$ ,  $s'$ ) with the measured values. The correction parameters are as follows:  $A$  for declination and compass mounting errors in azimuth;  $B$ ,  $C$  for hard and soft magnetic vehicle magnetism;  $A_2$  for mounting errors of the gradiometer in elevation; and  $\rho$  for a scale error of the odometer.

## Method to determine correction parameters

The invention concerns a method to determine correction parameters corresponding to the generic part of claim 1.

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When navigating a land vehicle by means of an electronic compass to indicate the azimuth, an inclinometer to indicate the elevation and height and an odometer to indicate the distance, errors will occur in the calculated position. The reasons for this are:

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- the difference between magnetic and cartographic North for the map used for the navigation,
- the geometric difference between the installed direction of the compass or inclinometer and the direction of travel of the vehicle,
- soft and hard magnetic influences of the vehicle on the compass, and
- scaling errors when measuring distances by means of an odometer.

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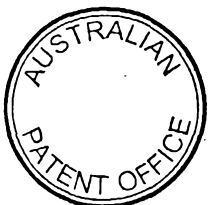
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For the purpose of navigation the direction of travel of the vehicle is used, expressed in coordinates of the cartographic North system, which is rotated additionally horizontally by the declination relative to the magnetic North system. The declination may be taken from tables. However, an additional rotation of the compass coordinate system is superposed on it relative to the direction of travel of the vehicle, whose direction is not known.

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In the case of a land vehicle the direction of travel of the vehicle is not stated with regard to the vehicle's chassis at the beginning by geometric or optical constructions or cannot be easily calculated according to the manufacturer's data. It



can be determined only empirically from the difference between the actual and calculated directions of travel.

5 From DE 41 25 369 A1 a navigation equipment mounted on a motor vehicle is known, which contains an Earth magnetism sensor as azimuth sensor. To compensate for the erroneous indications of this sensor due to the influences of a magnetic environment, a comparison with additionally obtained GPS navigation data is provided. With this, however, only a shifting of the zero-point  
10 of the coordinate system can be corrected.

DE 31 41 439 A1 discloses an azimuth-determining device, whereby the vehicle is aligned exactly to North and East with the azimuth sensor mounted on it. The deviation of the two-  
15 component measuring signals of the azimuth sensor established on this occasion relative to the specified orientation is compensated by adjusting the measuring signals with an adjustment circuit. Thus a distortion of the output signal based on the residual magnetism of the azimuth sensor is  
20 corrected also by the shifting of the zero point.

The influences of an erroneous orientation of a magnetic compass with regard to the direction of travel and of hard and soft magnetic fields on the accuracy of the display are known  
25 from shipping. To compensate for the deviation of the compass, coefficients *A*, *B*, *C*, *D*, *E* are defined and each is separately determined. On this occasion *A* takes into consideration a constant indication error by, for example, installing the compass rotated relative to the longitudinal direction of the  
30 ship, *B* considers the influence of the longitudinal magnetism of the ship, *C* the influence of the transverse magnetism of the ship, *D* the influence of a magnetism induced in soft iron parts and *E* an asymmetry of the distribution of the iron masses in the ship's body (A.Heine, Kompass ABC, Klasing+Co. publishers  
35 (1983), pages 43 to 45). Since the influences of *D* and *E* are generally small, their coefficients are generally neglected.

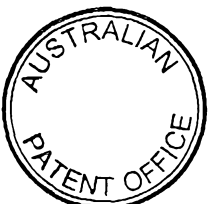


To determine the coefficients the ship is held at known courses towards North, East, South and West and each deviation of the compass display relative the known courses is read off. The individual coefficients are calculated by averaging the deviation values relative the selected courses.

The distance deviations occurring in land navigation by inaccurate measuring of the distances and by travelling in mountains relative to the distances shown on the map is irrelevant in shipping. For an autonomous navigation of land vehicles it is, however, necessary to equip them in addition to the magnetic compass for the directional measuring also with an odometer to measure the distance and an inclinometer, to enable the conversion of the distances measured when travelling in mountains or valleys to the corresponding values in the plane of the map.

Calibration of the compass display is usually carried out by driving in circles and registering measured values at several defined angular positions relative to the centre of the circle. Partly a correction of the magnetic directional display for the horizontal plane is also carried out with the aid of inclination sensors. In the case of a digital magnetic compass (DMC), manufactured by Leica AG, Heerbrugg, Switzerland, in addition to the three magnetic field sensors for the three spatial coordinates two inclination sensors for elevation and banking are also integrated. The measuring of distance and the position of the vehicle resulting from it, together with the measuring of the direction, can be checked with the aid of independently obtained satellite navigation signals (GPS) and, if necessary, corrected. The measuring of the direction, distance and position are carried out as systems independent from each other (Information pamphlet by KVH Industries, Inc., USA, (1995), TACNAV System).

The object of the invention is to specify a method which is simple to apply, with which in the case of a land vehicle the correction values for the azimuth, elevation and distance



measurements indicated by the installed measuring equipment can be determined, so that a considerably increased accuracy in the navigation is achieved and a GPS checking can be dispensed with.

5

This objective is achieved according to the invention by the features specified in the characterising part of claim 1. It is particularly advantageous for the evaluation if a two-way travel is carried out between two points whose geographic coordinates are known.

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In the drawing the direction of travel of the vehicle is illustrated as a vector relative to the horizontal plane = plane of the map, wherein

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Fig.1 - shows the azimuth and the elevation, and

Fig.2 - shows the influence of an azimuth error on the elevation reading.

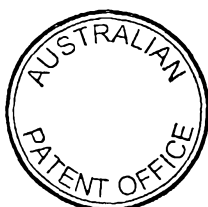
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The invention is described in the following example, wherein azimuth measurements and elevation measurements are carried out in a system (DMC) coupled with each other.

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Based on the azimuth and elevation values, the direction of travel  $\vec{L}'_F$  of the vehicle is illustrated as a unit vector in the horizontal plane and relative to the magnetic North. Fig.1 illustrates the interrelations, wherein  $e_F$  designates the angle of elevation between the actual direction of travel  $\vec{L}_F$  of the vehicle and of the horizontal plane, and  $a_F$  designates the azimuth angle between magnetic North and the projection of  $\vec{L}_F$  on the horizontal plane. By multiplying with the distance travelled  $s_F$ , in general representation the position in the horizontal plane is

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$$s_F \cdot \vec{L}_F^N = s_F \begin{pmatrix} \cos e_F \cdot \cos a_F \\ \cos e_F \cdot \sin a_F \\ \sin e_F \end{pmatrix}$$

5 In practice the position achieved is determined based on a point of departure by stringing together many intermediate values  $\vec{L}_j, s_j; j = 1 \dots N$ . In shipping this method is known as navigation by dead reckoning. Therefore by omitting the indices N and F for the position reached along the direction of travel  
10 of the vehicle the following is valid in the horizontal plane:

$$15 \int_0^s \vec{L} ds \approx \sum_{j=1}^N \vec{L}_j \cdot s_j = \sum_{j=1}^N \begin{pmatrix} \cos e_j \cdot \cos a_j \\ \cos e_j \cdot \sin a_j \\ \sin e_j \end{pmatrix} \cdot s_j$$

20 Other formulae of an approximating integration are feasible and are within the scope of knowledge of a person skilled in the art.

25 By assuming that the values available for the elevation  $e$ , azimuth  $a$  and distance  $s$  are correct and the point of departure is known, an accurate statement regarding the position can be made by evaluating the stated sum or by entering the values  $a$  and  $s$  taken from the map an accurate navigation can be carried out. In fact the values indicated by the measuring equipment are, however, distorted, as this has been explained at the  
30 beginning and is illustrated in Fig.2.

The elevation  $e$  and azimuth  $a$  are measured in the coordinate system of the DMC. Its x-axis is to correspond with the direction of travel of the vehicle. Fig.2 shows the azimuth shift  $\Delta a_p$  of the projection of the direction of travel  $\vec{L}_p$  of  
35 the vehicle relative to the projection of the x-axis and it shows the direction of the elevation  $e$  of the x-axis relative to the elevation  $e_p$  in the direction of travel of the vehicle.



According to the invention the measured values  $a$ ,  $e$ ,  $s$  are substituted by the corrected values  $a'$ ,  $e'$ ,  $s'$  in accordance with the following example:

5  $a' = a + A + B \cdot \sin a + C \cdot \cos a$

$$e' = e - A_2$$

$$s' = \rho \cdot s$$

On this occasion the parameters consider:

10

$A$  - the declination relative to the magnetic North and a compass installation error in the azimuth,

$B$ ,  $C$  - a hard and soft magnetic vehicle magnetism,

15

$A_2$  - an installation error of the inclinometer in elevation, and

$\rho$  - a scalar error of the odometer.

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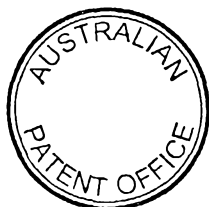
According to the invention the unknown correction parameters are determined in two visually navigated test drives, wherein the correct values of  $a'$ ,  $e'$  and  $s'$  between the departure and arrival positions are known and the actual values  $a$ ,  $e$ ,  $s$  are measured. Thus in each test drive a sufficient number of independent qualifying equations will result corresponding to the measured values for the three spatial coordinates  $x$ ,  $y$ ,  $z$ , so that the correction parameters can be unequivocally determined and can be taken into consideration in the measuring system in the case of a subsequent instrument-aided navigation drives.

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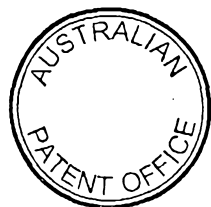
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It is particularly advantageous if a simple direction reversal is carried out in both test drives. For this only two points with their geographical coordinates need to be known and the actual difference in travel is zero, so that the system of qualifying equations is simplified.

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When using one vehicle on the level only, the use of inclinometers may be omitted. Thus the number of correction parameters is reduced and the solution of the qualifying equations is also simplified. It is obvious that this specialisation is not outside the concept of the invention. The important thing is to enable to describe the corrected azimuth in the given form and to enable to determine all necessary correction parameters, in the simplest case, with two test drives between two known points.



## Patent claims

1. A method to determine correction parameters for the measured values of a magnetic compass installed in a land vehicle for navigational purposes and indicating the azimuth  $a$  of the direction of travel of the vehicle, of an inclinometer indicating the elevation  $e$  of the direction of travel of the vehicle relative to the horizon and of an odometer indicating the distance travelled  $s$ , wherein the instant directional vector of the vehicle is stated as

$$\int_0^s \bar{L} ds \approx \sum_{j=1}^N \bar{L}_j \cdot s_j = \sum_{j=1}^N \begin{pmatrix} \cos e_j \cdot \cos a_j \\ \cos e_j \cdot \sin a_j \\ \sin e_j \end{pmatrix} \cdot s_j$$

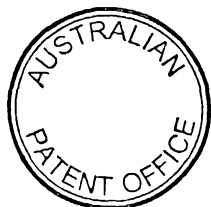
wherein  $L_j$  = direction of travel of the vehicle in the horizontal plane and  $s_j$  = travelled interval between two measured points  $j$  and  $j-1$ , characterised in

that a first test drive is carried out by visual navigation from a point of departure with known geographic coordinates to a point of arrival also with known geographic coordinates,

that a subsequent test drive is carried out changing its direction by visual navigation to a second point of arrival with known geographic coordinates,

that during the test drives at the times  $t_j$ ;  $j = 1 \dots N$ , the measured values  $a_j$ ,  $e_j$ ,  $s_j$  are recorded and from the known departure point and arrival point coordinates the corresponding values  $a'_j$ ,  $e'_j$ ,  $s'_j$  are calculated, and that the relationship between the calculated directional vectors and the measured directional vectors is expressed in accordance with

$$\begin{aligned} a' &= a + A + B \cdot \sin a + C \cdot \cos a \\ e' &= e - A_2 \\ s' &= \rho \cdot s \end{aligned}$$



and from this correction parameters

5 A - for declination and compass installation error in the  
azimuth,

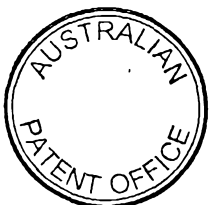
B, C - for hard and soft magnetic vehicle magnetism,

10  $A_2$  - for installation error of the inclinometer in  
elevation, and

$\rho$  - for a scalar error of the odometer.

are determined.

15 2. A method according to claim 1, characterised in that the  
second test drive takes place from the first point of  
arrival back to the point of departure.



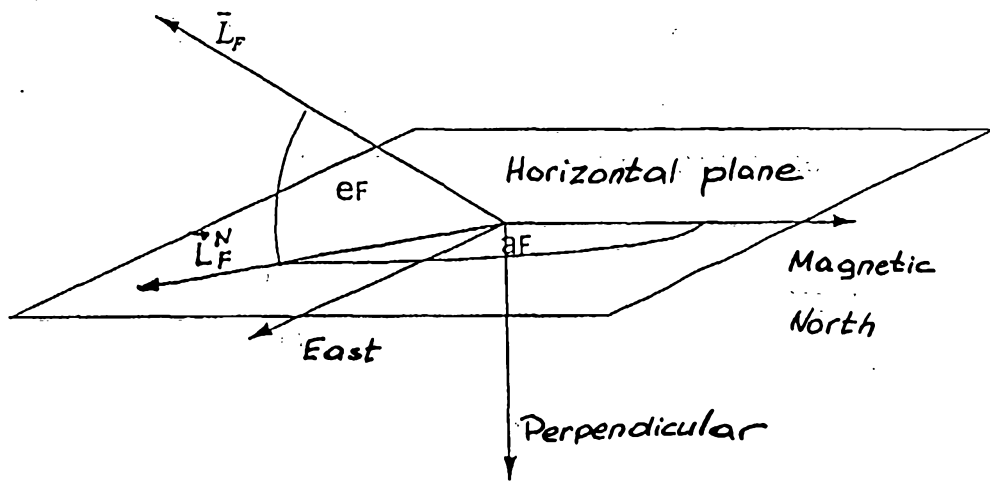


Fig. 1

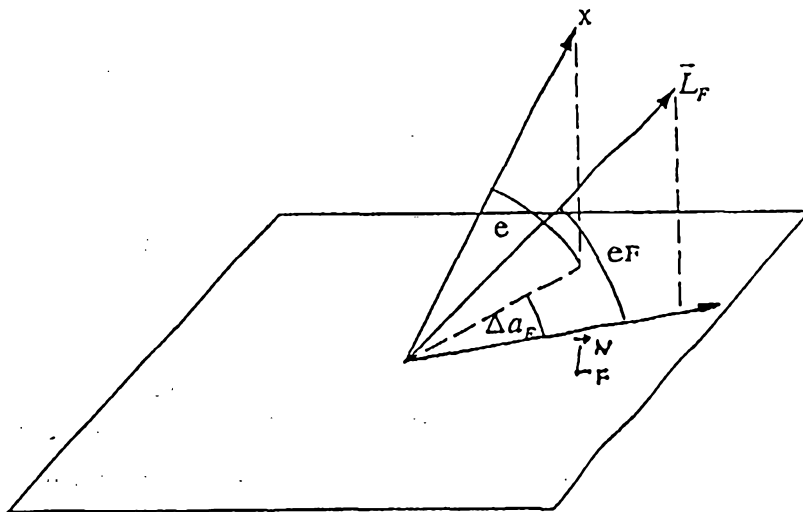


Fig. 2