(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
24 January 2008 (24.01.2008)

PCT

(10) International Publication Number
WO 2008/010046 A2

(51) International Patent Classification: Not classified

(21) International Application Number: PCT/IB2007/001939

(22) International Filing Date: 11 July 2007 (11.07.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2006-193243 13 July 2006 (13.07.2006) JP

(71) Applicant (*for all designated States except US*): **TOYOTA JIDOSHA KABUSHIKI KAISYA** [JP/JP]; 1, Toyota-cho, Toyota-shi, Aichi-ken, 471-8571 (JP).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **KOBORI, Norimasa** [JP/JP]; c/o Toyota Jidosha Kabushiki Kaisha, of 1, Toyota.cho, Toyota-shi, Aichi-ken 471-8571 (JP). **KAGAWA, Kazunori** [JP/JP]; c/o Toyota Jidosha Kabushiki Kaisha, of 1, Toyota.cho, Toyota-shi, Aichi-ken 471-8571 (JP).

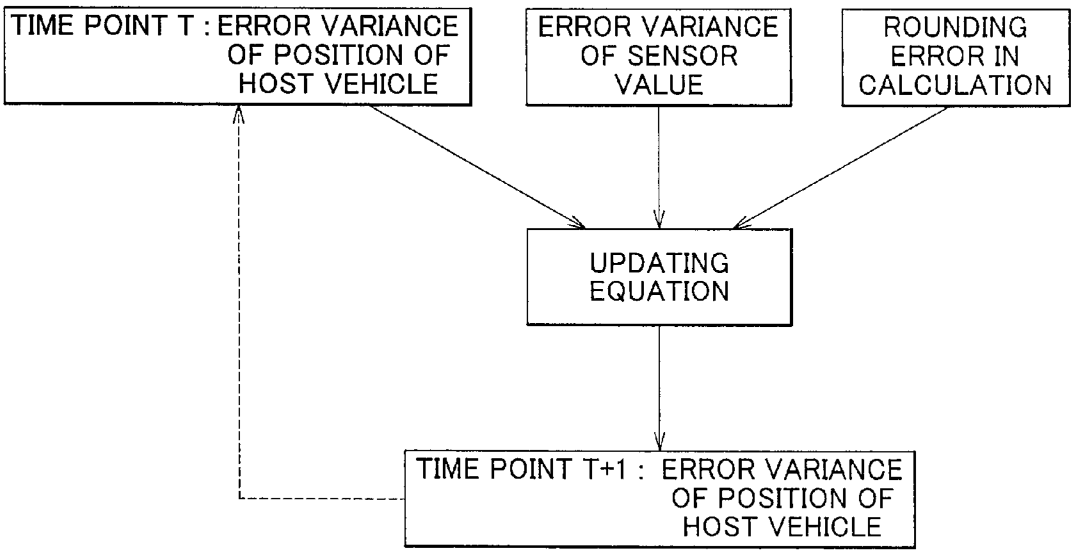
(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: NAVIGATION APPARATUS



(57) Abstract: A navigation apparatus (1) that detects a position of a movable body includes an autonomous sensor (12, 13) that detects information on behavior of the movable body; inertial position determination means (10a) for detecting an inertial position-determination position of the movable body by accumulating the information detected by the autonomous sensor (12, 13); and error variance calculation means (10b) for recursively calculating an error variance of the inertial position-determination position at time point t+1, by applying the error variance, a sensor error variance due to the autonomous sensor (12, 13), and a calculation error at time point t, to an updating equation based on a movement model of the movable body.

WO 2008/010046 A2

NAVIGATION APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The invention relates to a navigation apparatus that detects the position of a movable body. More specifically, the invention relates to a navigation apparatus that evaluates position determination performed using inertial navigation, and the error of the position determination.

2. Description of the Related Art

[0002] In a navigation apparatus, radio navigation and inertial navigation are used. In the radio navigation, the position of a host vehicle is detected based on radio waves from GPS (Global Positioning System) satellites. In the inertial navigation, the position of the host vehicle is detected using a behavior sensor that detects behavior of the host vehicle, such as a velocity.

[0003] However, it is known that a large or small error is included in the position determination performed using radio navigation or inertial navigation. Thus, when various vehicle controls are executed using the position of the host vehicle, the degree of the error may influence the various vehicle controls.

[0004] Therefore, a method of evaluating the error of the position determination performed using radio navigation and a method of evaluating the error of the position determination performed by inertial navigation are needed. With regard to the position determination performed using radio navigation, the error may be small, or even if the error is large, there is a conventional method of evaluating the error of the position determination performed by radio navigation.

[0005] Also, a method of evaluating the error with regard to the position determination performed using inertial navigation is proposed (for example, refer to Japanese Patent Application Publication No. 10-54729 (JP-A-10-54729)). In the method of evaluating the error described in JP-A-10-54729, the accuracy of the determination of the position of a host vehicle is estimated, based on the errors of the travel distance and direction of the host vehicle detected by a distance sensor and a direction sensor, respectively, an calculation error caused when the travel direction of the host vehicle is not constant, the accumulated errors of the travel distance and direction, and the accumulated calculation error. The estimation is made according to the accuracy of the sensors, using probability distribution. Thus, using probability distribution, it is possible to evaluate the error of the position determined using inertial navigation.

[0006] However, in the evaluation method described in JP-A-10-54729, only the errors caused by the distance sensor and the direction sensor are taken into account, and factors that influence the position of the movable body are not sufficiently examined. For example, when the vehicle is traveling, the position of the vehicle is changed by the influence associated with the attribute of the vehicle, such as the center of gravity of the vehicle. Therefore, the error determined taking into account only the distance sensor and the direction sensor is not sufficient for evaluating the error of the position determination performed using inertial navigation.

SUMMARY OF THE INVENTION

[0007] The invention provides a navigation apparatus that accurately evaluates an error with regard to position determination performed using inertial navigation.

[0008] A first aspect of the invention relates to a navigation apparatus that detects the position of a movable body. The navigation apparatus includes an autonomous sensor that detects information on behavior of the movable body; inertial position determination means for detecting an inertial position-determination position of the movable body by accumulating the information detected by the autonomous sensor; and error variance calculation means for recursively calculating an error variance of the inertial position-determination position at time point t+1, by applying the error variance, a sensor error variance due to the autonomous sensor, and a calculation error at time point t, to an updating equation based on a movement model of the movable body. As the movement model of the movable body, for example, a dynamics model may be used.

[0009] According to the first aspect, it is possible to provide the navigation apparatus that accurately evaluates the error with regard to the position determination performed by inertial navigation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The above and other objects and features of the present invention will become apparent from the following description of example embodiments given in conjunction with the accompanying drawings, in which:

FIG. 1 is a diagram showing the outline of error evaluation on the position of a host vehicle;

FIGS. 2A and 2B are schematic configuration diagrams showing a navigation apparatus;

FIG. 3 is a diagram showing an example of a dynamics model;

FIG. 4 is a diagram showing an example of the result of position determination performed by inertial navigation, and an error variance;

FIG. 5 is a diagram showing the outline of the determination of the position of the host vehicle using a reliability error ellipsoid; and

FIG. 6 is a diagram showing the result of the determination as to whether the host vehicle was in the intersection of a road on which the host vehicle actually traveled, based on the reliability error ellipsoid.

DETAILED DESCRIPTION OF THE EXAMPLE EMBODIMENTS

[0011] Hereinafter, a first aspect of the invention will be described with reference to the drawings. First, the outline of error evaluation on the position of a host vehicle will be described.

[0012] FIG. 1 is a diagram showing the outline of the error evaluation on the position of the host vehicle. In the embodiment, an error variance is used as the error evaluation. Then, the error variance of the position of the host vehicle at time point t+1 is calculated by applying the error variance, the error variance of a sensor value, and a rounding error in calculation at time point t, to an updating equation.

[0013] Instead of simply accumulating the error of the sensor value, the error variance of the position of the host vehicle is recursively derived using the updating equation. Therefore, it is possible to accurately evaluate the error of the position of the host vehicle. Also, the updating equation is set based on the dynamics model of the vehicle. Therefore, it is possible to derive the error of the position determination in accordance with the property of the movable body.

[0014] FIG. 2A is a schematic configuration diagram showing a navigation apparatus 1. The navigation apparatus 1 is controlled by a navigation ECU (Electronic Control Unit) 10. The navigation ECU 10 is configured as a computer in which a CPU that executes programs, storage devices (a hard disk drive, and ROM) that store the programs, RAM that temporarily stores data and the programs, an input/output portion to/from which data is input/output, NV-RAM (Nonvolatile-RAM), and the like are connected with each other by a bus.

[0015] The navigation ECU 10 is connected to a GPS receiver 11 that receives radio waves from GPS satellites; vehicle speed sensors 12 that detect the vehicle speed; a yaw-rate sensor 13 that detects the rotational angular velocity of the vehicle around a vertical axis; a map database (hereinafter, referred to as "map DB") 14 that stores map data; an input device 15 that is used to operate the navigation apparatus 1; and a display 16 that displays the current position of the host vehicle. The other autonomous sensors, such as a gyro sensor and a steering-angle sensor, may be provided.

[0016] The GPS receiver 11 outputs the position of the host vehicle based on the radio waves from the GPS satellites, using a known method. The GPS receiver 11 calculates distances from the host vehicle to the GPS satellites, based on times required for the radio waves transmitted from the plurality of GPS satellites to reach the GPS receiver 11. Then, the GPS receiver 11 determines an intersection of three hyperboloids defined using the loci of the distances from the respective at least three GPS satellites to the host vehicle, as the position of the host vehicle.

[0017] The vehicle speed sensor 12 outputs a pulse signal according to the rotation of a tire. The vehicle speed is detected based on the number of pulses detected in each sampling time period. The relation between the pulse number and a travel distance is calculated in advance as a pulse coefficient using the relation "travel distance ÷ pulse number" when the travel distance is known. However, when the air pressure in the tire (the diameter of the tire) is changed, the pulse coefficient is changed. Also, when the travel distance is detected using the pulse at a low vehicle speed, an error may be caused.

[0018] The yaw-rate sensor 13 generates voltage or the like that is proportional to the rotational angular velocity of the vehicle around the vertical axis. The output from the yaw-rate sensor 13 is converted from the voltage or the like, to the rotational angular velocity, using a proportional constant. In the yaw-rate sensor 13, when the detection shaft attached to the vehicle body does not match the turning axis of the vehicle, the proportional constant, which is determined in advance, differs from an actual conversion proportion. As a result, the rotational angular velocity including an error is output. Also, because the yaw-rate sensor 13 is disposed such that the detection shaft extends along a predetermined direction (for example, in the direction of gravity when the vehicle is on a horizontal road), when the vehicle turns on an inclined surface, the conversion proportion is changed, and an error is caused.

[0019] The map DB 14 is constituted by the hard disk, CD-ROM, DVD-ROM, and the like. The map DB 14 stores road map information on a road network, intersections, and the like, which is associated with the latitudes and longitudes. In the map DB 14, information relating to nodes (for example, points at which roads intersect with each other, and points at predetermined intervals from intersections), and information relating to links (i.e., roads which connect the nodes), which are associated with an actual road network, are stored in respective table databases.

[0020] The input device 15 is constituted by a touch panel, a press-type keyboard, buttons, a remote control, a cross key, and the like. The input device 15 is an interface to which operation performed by a driver is input. The input device 15 may include a microphone, and may recognize the voice of the driver using a voice recognition circuit so that operation is input to the input device 15. When a search for a route to a destination is conducted, the driver may input the destination using an address, a geographic name, the name of a landmark, a post code, and the like.

[0021] The display device 16 is constituted by a liquid crystal display, an organic EL display, a HUD (Head Up Display), or the like. The display device 16 displays a road map showing an area around the host vehicle, or a road map showing a designated area on a designated scale. In addition, the display device 16 displays the position of the host vehicle, the route to the destination, and the like on the road map, as needed. The display device 16 includes a speaker, and gives voice guidance on the orientation of the vehicle along the route using the speaker, for example, at an intersection at which the vehicle turns to the right or left.

[0022] FIG. 2B is a function block diagram of the navigation ECU 10. When the CPU of the navigation ECU 10 executes a program, inertial position determination means 10a, error variance calculation means 10b, error ellipsoid calculation means 10c, and determination means 10d are realized. The inertial position determination means 10a detects the determined position of the host vehicle by accumulating information detected by the vehicle speed 12 and the yaw-rate sensor 13. The error variance calculation means 10b recursively derives the error variance of the determined position based on the dynamics model. The error ellipsoid calculation means 10c calculates a reliability error ellipsoid. The determination means 10d determines whether the reliability error ellipsoid overlaps a predetermined region. The dynamics model and a Mahalanobis distance described later are stored in the storage device of the navigation ECU 10.

[0023] In the embodiment, the inertial position determination means 10a detects (estimates) the determined position of the host vehicle by accumulating the information detected by the vehicle speed 12 and the yaw-rate sensor 13, using a known method. Then, the error variance calculation means 10b calculates the error variance of the determined position.

[0024] [Derivation of error variance using updating equation] The derivation of the error variance performed by the error variance calculation means 10b will be described in detail. In the embodiment, the dynamics model for estimating the position of the vehicle is set. When positional information and sensor information on the host vehicle at time point t are input to the dynamics model, the dynamics model outputs the estimated position at time point t+1. Thus, by modifying the dynamics model, the error variance of the estimated position at time point t+1 is derived from the error variance at time point t. The dynamics model will be described later.

[0025] The true position and direction X_t, and the translational velocity and rotational angular velocity U_t are represented as follows (each of X_t and U_t is a vector quantity). The translational velocity is not the vehicle velocity in the orientation of the vehicle. The translational velocity is the vehicle velocity in a vehicle-length direction and a vehicle-width direction.

[0026]

$X_t = (x, y, \theta)$

$U_t = (v_t, w_t)$

When the equation for estimating the position of the host vehicle through the input of X_t and U_t is $f(X_t, U_t)$ (hereinafter, simply referred to as "dynamics model"), the position X_{t+1} of the host vehicle at time point t+1 is represented as follows.

[0027]

$X_{t+1} = f(X_t, U_t) + n_t \ldots (1)$

Note that "n_t" represents an error due to quantization and the rounding error in the calculation.

[0028] The error of X_t is represented by ΔX_t, the error of U_t is represented by ΔU_t, the estimated value (average value) of X_t is represented by $X^\wedge_t$, and the estimated value (average value) of Ut is represented by $U^\wedge_t$.

[0029] Also, a host-vehicle position estimating equation is defined as follows.

[0030]

$X^\wedge_{t+1} = f(X^\wedge_t, U^\wedge_t) \ldots (2)$

Talor expansion is applied to linealize the equation (2).

[0031]

$$X_{t+1} = f(X_t, U_t) + n_t$$

$$= f(X^\wedge_t + \Delta X_t, U^\wedge_t + \Delta U_t) + n_t$$

$\approx f(X\hat{}_t, U\hat{}_t) + Jx\Delta X_t + J_u\Delta U_t + n_t$

$= X\hat{}_{t+1} + \Delta X_{t+1}$

Note that J_x and J_u are represented as follows, and the relation in the equation (2) is used in the third and fourth lines.

[0032]

$$J_X = \left.\frac{\partial f(X,U)}{\partial X}\right|_{\substack{X=Xt \\ U=Ut}} \qquad J_U = \left.\frac{\partial f(X,U)}{\partial X}\right|_{\substack{X=Xt \\ U=Ut}}$$

[0033] Because the following relation is obtained from the third and fourth lines, the updating equation for deriving the error variance is obtained from this equation.

$\Delta X_{t+1} = J_x\Delta X_t + J_u\Delta U_t + n_t$

Thus, the error variance of the estimated position is represented as follows. The equation (3) is the updating equation for recursively deriving the error variance. Note that $\Sigma_{Xt} = E(\Delta X_t \Delta X_t^T)$, $\Sigma_{Ut} = E(\Delta U_t \Delta U_t^T)$, $\Sigma_n = E(\Delta_n \Delta_n^T)$. (The upper right superscript "T" indicates a transposed matrix). "E" is a sign indicating an expected value. Accordingly, "Σ" indicates a covariance matrix.

[0034]

$$\sum_{X_{t+1}} = J_X \sum_{Xt} J_X^T + J_U \sum_U J_U^T + \sum_n \qquad \ldots(3)$$

[0035] Each of the first to third terms indicates as follows.

[0036]

The first term: the amount of influence of the error of the estimated position at time point t on the error of the estimated position at time point t+1.

The second term: the error of the sensor value.

The third term: the error due to the rounding error in the calculation, and the other factors.

Accordingly, as shown by the updating equation, the error variance of the estimated position is recursively derived by determining Σ_{X0}, Σ_{U0}, Σn at time point t = 0.

[0037] [Dynamics model] Subsequently, the dynamics model will be described. FIG. 3 is a diagram showing a geometric vehicle model as one example of the dynamics model. The dynamics model according to the embodiment is an example. The other models appropriately set may be appropriately used to derive the error variance according to the embodiment.

[0038] In the dynamics model in FIG. 3, a vehicle 20 is a four-wheel vehicle. However, for explanation, three wheels, that is, a front-side Fc (steering wheel), rear wheels Rl and Rr, are shown. The overall length L of the vehicle is represented by the equation, L = Lf (front side) + Lr (rear side) with respect to the gravity center.

[0039] Hereinafter, the translational velocity v_t of the vehicle, and the rotational angular velocity w_t at the gravity center will be obtained.

A. The vehicle velocity, which is the average of the velocities of the four wheels detected by the vehicle-velocity sensors 12, is approximated to a vehicle velocity Vstr.

B. The vehicle velocity Vstr is decomposed into a velocity in the vehicle-length direction, and a velocity in the vehicle-width direction. To decompose the vehicle velocity Vstr, a steering angle α is detected by the steering-angle sensor.

[0040]

i) The velocity in the vehicle-length direction [m/s]

$V\_model\_x = Vstr \times \cos(\alpha)$

ii) The velocity in the vehicle-width direction [m/s]

$V\_model\_fy = Vstr \times \sin(\alpha)$

C. The translational velocity and rotational angular velocity at the gravity center are calculated. On the assumption that the translational velocity in the lateral direction at the position of the rear wheels of the vehicle is zero, the translational velocity and rotational angular velocity at the position of the gravity center are calculated according to the distance from the position of the front wheels to the gravity center.

[0041]

i) A coefficient set according to the distance from the position of the front wheels to the position of the gravity center.

K_wheelbase = Lr / L

ii) The translational velocity in the vehicle-length direction at the gravity center [m/s]

V_model_x

iii) The translational velocity in the vehicle-width direction at the gravity center [m/s]

V_model_gy = V_model_fy × K_wheelbase

iv) The rotational angular velocity at the gravity center [rad/s]

yaw_model_g = V_model_fy / L

Thus, V_t and W_t are represented as follows.

[0042]

$$Vt = \begin{pmatrix} \text{V\_model\_x} \\ \text{V\_model\_gy} \end{pmatrix} \qquad Wt = \text{yaw\_model\_g}$$

[0043]

The true position and direction X_t of the vehicle is calculated from the translational velocity and rotational angular velocity. That is, the amount of change based on the translational velocity and rotational angular velocity is accumulated on the previous position and direction. Note that "S_t" represents a sampling time period.

[0044]

$x_{t+1} = x_t + \text{V\_model\_x} \times S_t$

$y_{t+1} = y_t + \text{V\_model\_gy} \times S_t$

$\theta_{t+1} = \theta_t + w_t \times S_t$

Thus, by setting the dynamics model, it is possible to derive the function form (dynamics model) for calculating the true position and direction of the vehicle, and the translational velocity and rotational angular velocity of the vehicle.

[0045] According to the embodiment, it is possible to recursively derive the error variance of the (estimated) position of the host vehicle at time point t+1 by applying the error variance, the error variance of the sensor value, and the rounding error in the calculation at time point t, to the updating equation. Using the error variance, it is possible to accurately evaluate the error with regard to the position determination performed by inertial navigation.

[0046] FIG. 4 is a diagram showing an example of the result of the position determination performed using inertial navigation, and the error variance. The host vehicle is at a true position O, and travels toward an intersection P. Error variance Qv, which is derived by the updating equation, and shown by the dotted line, is obtained with respect to a position Q determined using inertial navigation. An intersection region Pv, which is a concentric region around the node P of the intersection, is shown to indicate the region of the intersection P.

[0047] According to the determined position Q, the host vehicle is not in the intersection region Pv. However, because the determined position Q includes an error, the host vehicle may be actually in the intersection region Pv.

[0048] Accordingly, for example, in the case where an alarm is provided to draw the driver's attention when the host vehicle is in the intersection, the determination based on only the determined position Q is not sufficient.

[0049] In contrast, in the embodiment, not only the determined position Q, but also the error variance Qv of the estimated position is derived. Therefore, when the error variance Qv overlaps the intersection region Pv, it is detected that there is a possibility that the host vehicle is in or near the intersection.

[0050] According to the embodiment, when the position of the host vehicle is detected using inertial navigation, the region where the host vehicle may be positioned is detected. Thus, it is possible to accurately control the vehicle. Also, the region where the host vehicle may be positioned is derived based on the dynamics model formed taking into account factors that influence the position of the movable body. Therefore, it is possible to appropriately evaluate the error of the position determination performed using inertial navigation.

Hereinafter, a second embodiment of the invention will be described with a focus on the differences between the second embodiment and the first embodiment.

[0051] In the case where the determined position Q of the host vehicle and the error variance Qv are obtained as shown in FIG. 4, even when the host vehicle is far from the intersection, it may be determined that the host vehicle is in the intersection, depending on the error variance Qv.

[0052] Accordingly, in the embodiment, a reliability error ellipsoid is calculated using a Mahalanobis distance D. Then, it is determined whether the host vehicle is in the intersection region Pv, based on whether the reliability error ellipsoid overlaps the intersection region Pv.

[0053] FIG. 5 is a diagram showing the outline of the determination of the position of the host vehicle using the reliability error ellipsoid. As shown in FIG. 5, to generate the reliability error ellipsoid, "the (estimated) position of the host vehicle", "the error variance of the position of the host vehicle" and "the existing probability of the host vehicle (Mahalanobis distance D)" are used.

[0054] The equation for calculating the reliability error ellipsoid is as follows.

Reliability error ellipsoid = $(X - X^*)^T \Sigma_{Xt}^{-1} (X - X^*) = D$ ... (4)

"X^*" represents "the (estimated) position of the host vehicle", and "Σ_{Xt}" represents "the error variance of the position of the host vehicle (the first term of the updating equation)". Therefore, the error ellipsoid calculation means 10c determines the reliability error ellipsoid by assuming an appropriate existing probability, and inputting the Mahalanobis distance D.

[0055] The determination means 10d extracts the positional information on the intersection node from the map DB 14, and determines a region having a predetermined radius as the intersection region Pv, according to the width of a road, or the like.

[0056] When the reliability error ellipsoid overlaps the intersection region Pv, the determination means 10d determines that the host vehicle is in the intersection. When the reliability error ellipsoid does not overlap the intersection region Pv, the determination means 10d determines that the host vehicle is not in the intersection.

[0057] FIG. 6 is a diagram showing the result of the determination as to whether the host vehicle was in the intersection of a road on which the host vehicle actually traveled, based on the reliability error ellipsoid.

[0058] The host vehicle travels from an upper left region toward the intersection in the direction shown by the arrow, and the host vehicle turns to the right at the intersection, and then the host vehicle travels downward in FIG. 6. When the vehicle is traveling, the navigation ECU calculates the reliability error ellipsoid at predetermined time intervals. Therefore, a plurality of the reliability error ellipsoids is shown. Because the reliability error ellipsoid shows the error variance of the determined position as described above, the plurality of reliability error ellipsoids is calculated along the locus of the determined positions.

[0059] Travel experiments were conducted to make the determination as to whether it was determined that the host vehicle was in the shown intersection based on the reliability error ellipsoid. That is, it was determined whether at least part of the reliability error ellipsoid overlapped the intersection region during the period until the host vehicle passed the intersection, that is, during the period in which the host vehicle was actually in the intersection. It was confirmed by visual observation that the host vehicle was actually in the intersection.

[0060] The travel experiments were conducted twenty times. For comparison, travel experiments were conducted twenty times to make the determination based on only the determined position, without taking into account the error of the determined position.

[0061] In the case where the determination was made based on the reliability error ellipsoid, it was determined that the host vehicle was in the intersection region in all of the twenty travel experiments. In contrast, in the case where the determination was made based on only the determined position, without taking into account the error of the determined position, it was determined that the host vehicle was in the intersection in the fourteen travel experiments out of the twenty travel experiments. However, it was determined that the host vehicle was not in the intersection even when the host vehicle was actually in the intersection in the six travel experiments. The results of the experiments show that the determination based on the reliability error ellipsoid is effective.

[0062] According to the embodiment, it is possible to reliably determine whether the host vehicle is in a predetermined position. Because the size of the reliability error ellipsoid is controlled using the Mahalanobis distance D, it is possible to minimize the possibility that an erroneous determination is made, for example, the possibility that it is erroneously determined that the host vehicle is in an intersection when the host vehicle is actually far from the intersection.

CLAIMS:

1. A navigation apparatus that detects a position of a movable body, comprising:

an autonomous sensor that detects information on behavior of the movable body;

inertial position determination means for detecting an inertial position-determination position of the movable body by accumulating the information detected by the autonomous sensor; and

error variance calculation means for recursively calculating an error variance of the inertial position-determination position at time point t+1, by applying the error variance, a sensor error variance due to the autonomous sensor, and a calculation error at time point t, to an updating equation based on a movement model of the movable body.

2. The navigation apparatus according to claim 1, wherein the movement model of the movable body is a dynamics model of the movable body.

3. The navigation apparatus according to claim 1 or 2, wherein the autonomous sensor includes at least one of a vehicle speed sensor, a yaw-rate sensor, a gyro sensor, a steering-angle sensor.

4. The navigation apparatus according to any one of claims 1 to 3, wherein the error variance calculation means calculates the error variance, based on the updating equation:

the error variance at time point t+1 = $J_X E(\Delta X_t \Delta X_t^T) J_X^T + J_U E(\Delta U_t \Delta U_t^T) J_U^T + E(\Delta n \Delta n^T)$, wherein:

X represents a position, U represents a value detected by the autonomous sensor, n represents a rounding error in calculation, ΔX_t represents an error of X, and ΔU_t represents an error of U; and

when the movement model is f (X, U), J_X and J_U are represented by equations:

$$J_X = \left.\frac{\partial f(X,U)}{\partial X}\right|_{\substack{X=Xt \\ U=Ut}} \qquad J_U = \left.\frac{\partial f(X,U)}{\partial X}\right|_{\substack{X=Xt \\ U=Ut}}$$

5. The navigation apparatus according to any one of claims 1 to 4, further comprising determination means for determining whether the movable body is in a predetermined region, based on whether at least part of the error variance overlaps the predetermined region.

6. The navigation apparatus according to any one of claims 1 to 4, further comprising:

error ellipsoid calculation means for calculating a reliability error ellipsoid, using the inertial position-determination position, the error variance, and a Mahalanobis distance; and

determination means for determining whether the movable body is in a predetermined region based on whether at least part of the reliability error ellipsoid overlaps the predetermined region.

7. A method of determining a position of a movable body, comprising:

detecting information on behavior of the movable body;

detecting an inertial position-determination position of the movable body by accumulating the information on the behavior; and

recursively calculating an error variance of the inertial position-determination position at time point t+1, by applying the error variance, an error variance of the information on the behavior, and a calculation error at time point t, to an updating equation based on a movement model of the movable body.

8. The method according to claim 7, wherein the error variance is calculated based on the updating equation:

the error variance at time point t+1 = $J_X E(\Delta X_t \Delta X_t^T) J_X^T + J_U E(\Delta U_t \Delta U_t^T) J_U^T + E(\Delta n \Delta n^T)$, wherein:

X represents a position, U represents a value detected by the autonomous sensor, n represents a rounding error in calculation, ΔX_t represents an error of X, and ΔU_t represents an error of U; and

when the movement model is f (X, U), J_X and J_U are represented by equations:

$$J_X = \left.\frac{\partial f(X,U)}{\partial X}\right|_{\substack{X=Xt \\ U=Ut}} \qquad J_U = \left.\frac{\partial f(X,U)}{\partial X}\right|_{\substack{X=Xt \\ U=Ut}}$$

9. The method according to claim 7 or 8, further comprising determining whether the movable body is in a predetermined region, based on whether at least part of the error variance overlaps the predetermined region.

10. The method according to claim 7 or 8, further comprising:

calculating a reliability error ellipsoid, using the inertial position-determination position, the error variance, and a Mahalanobis distance; and

determining whether the movable body is in a predetermined region based on whether at least part of the reliability error ellipsoid overlaps the predetermined region.

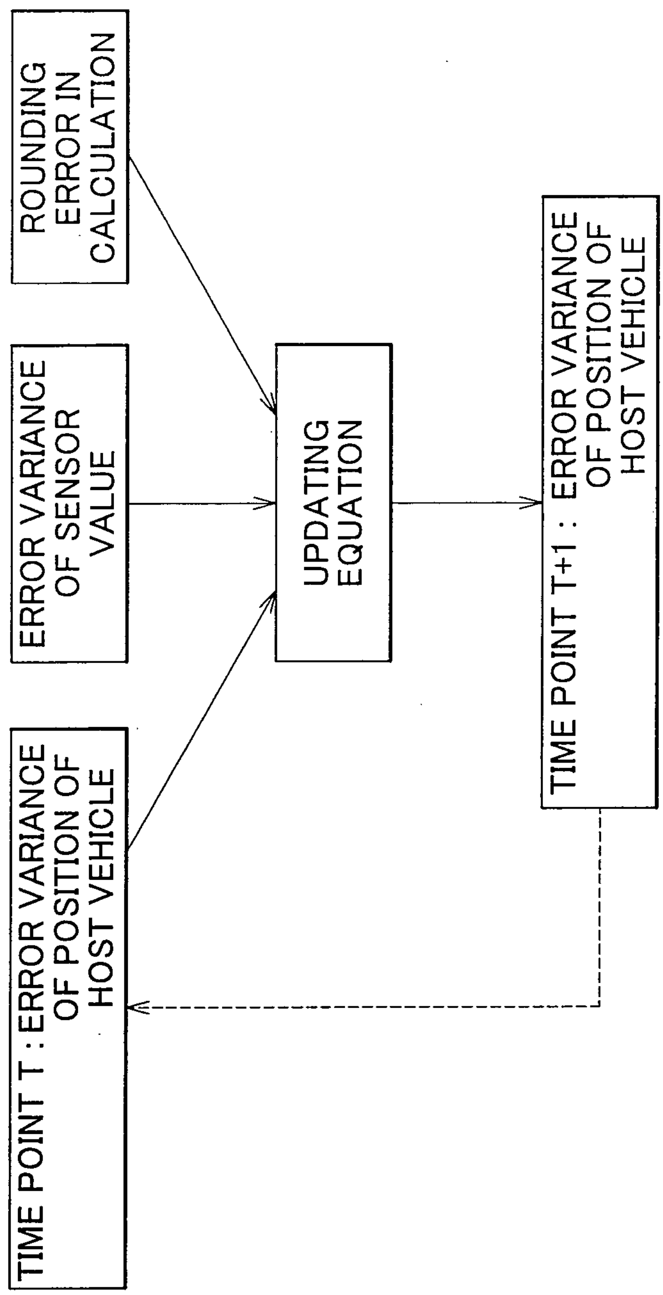
11. A navigation apparatus that detects a position of a movable body, comprising:

an autonomous sensor that detects information on behavior of the movable body;

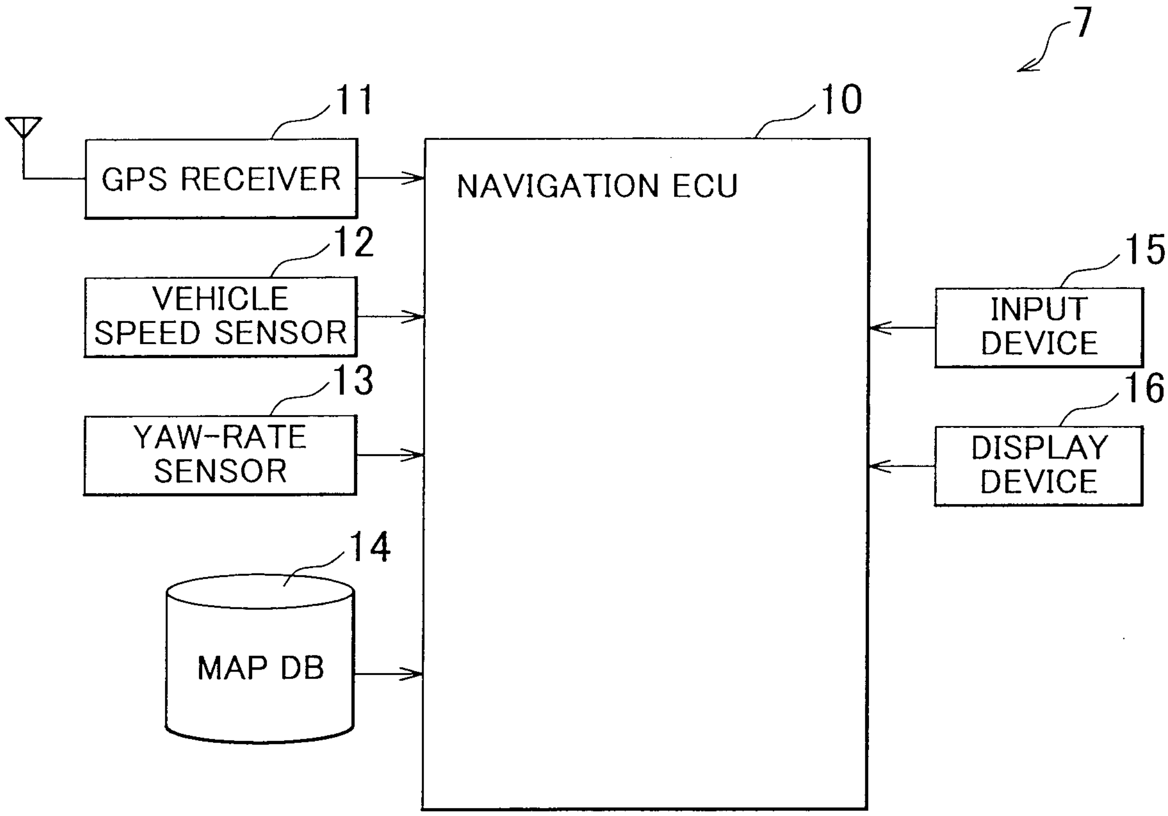
an inertial position determination portion that detects an inertial position-determination position of the movable body by accumulating the information detected by the autonomous sensor; and

an error variance calculation portion that recursively calculates an error variance of the inertial position-determination position at time point t+1, by applying the error variance, a sensor error variance due to the autonomous sensor, and a calculation error at time point t, to an updating equation based on a movement model of the movable body.

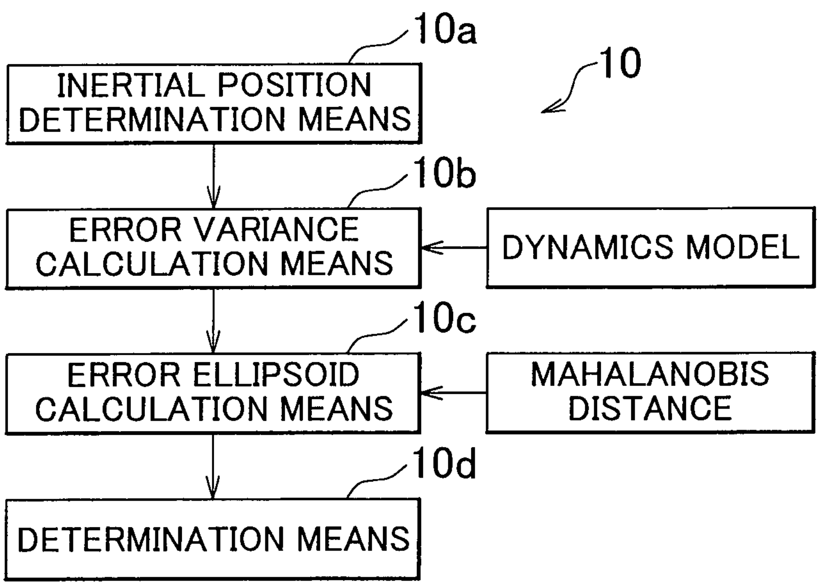
FIG. 1


ROUNDING ERROR IN CALCULATION
ERROR VARIANCE OF SENSOR VALUE
TIME POINT T : ERROR VARIANCE OF POSITION OF HOST VEHICLE
UPDATING EQUATION
TIME POINT T+1 : ERROR VARIANCE OF POSITION OF HOST VEHICLE

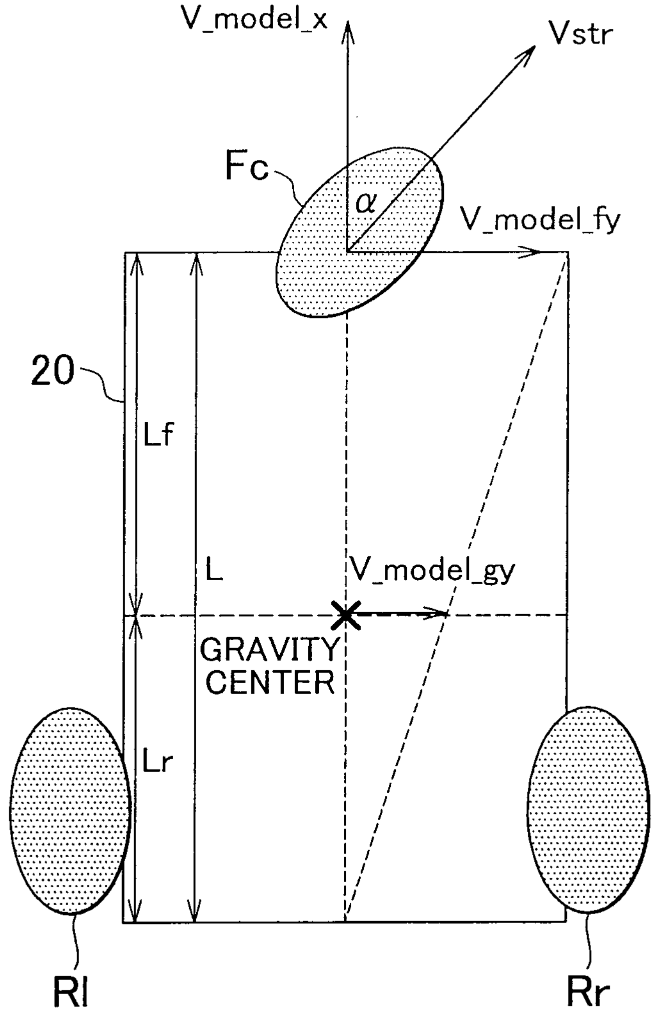
F I G . 2A


7
11
GPS RECEIVER
10
NAVIGATION ECU
12
VEHICLE SPEED SENSOR
13
YAW-RATE SENSOR
14
MAP DB
15
INPUT DEVICE
16
DISPLAY DEVICE

F I G . 2B


10a
INERTIAL POSITION DETERMINATION MEANS
10
10b
ERROR VARIANCE CALCULATION MEANS
DYNAMICS MODEL
10c
ERROR ELLIPSOID CALCULATION MEANS
MAHALANOBIS DISTANCE
10d
DETERMINATION MEANS

F I G . 3


V_model_x
Vstr
Fc
α
V_model_fy
20
Lf
L
V_model_gy
GRAVITY CENTER
Lr
Rl
Rr

F I G . 4

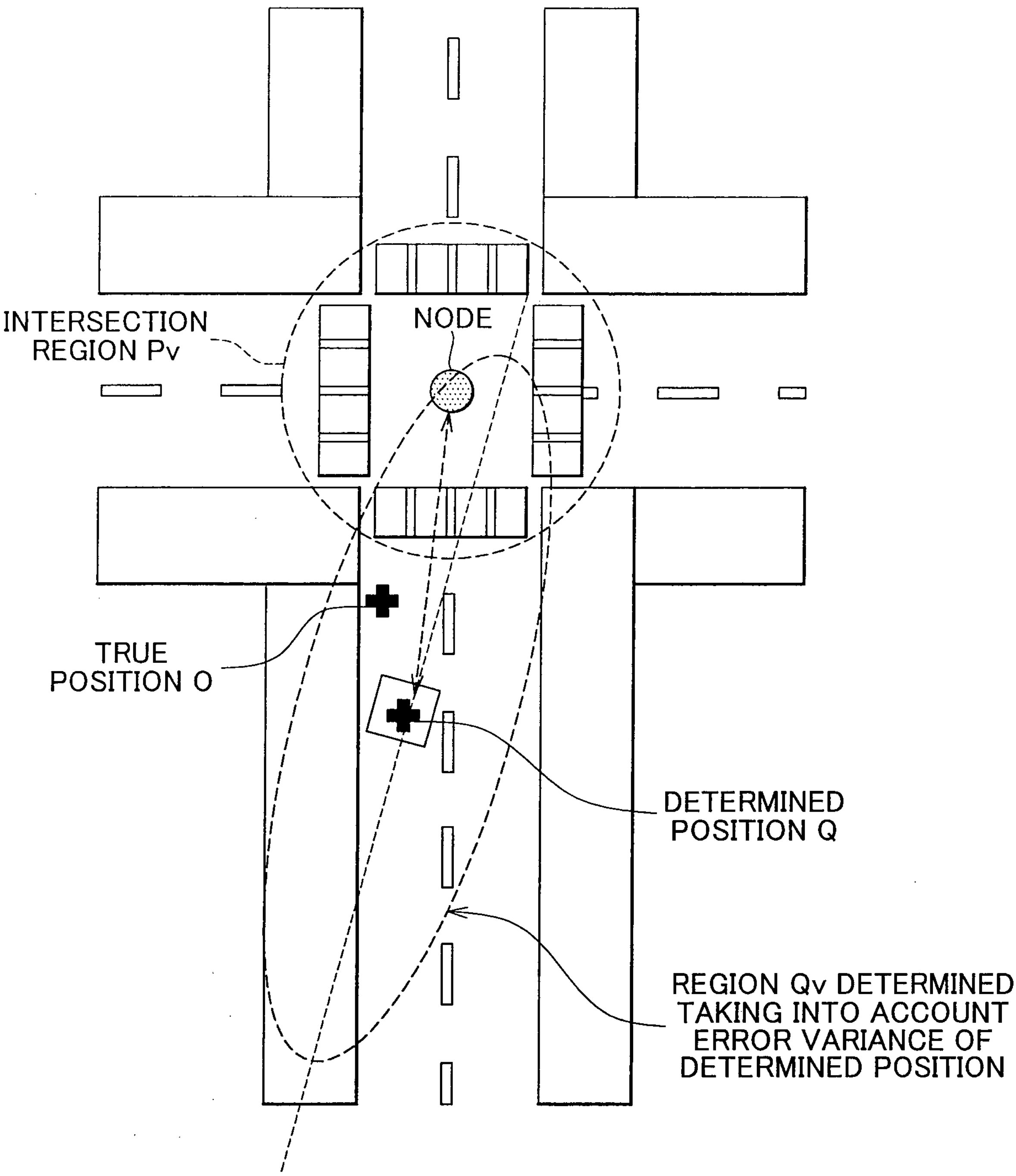

INTERSECTION REGION Pv
NODE
TRUE POSITION O
DETERMINED POSITION Q
REGION Qv DETERMINED TAKING INTO ACCOUNT ERROR VARIANCE OF DETERMINED POSITION

FIG. 5

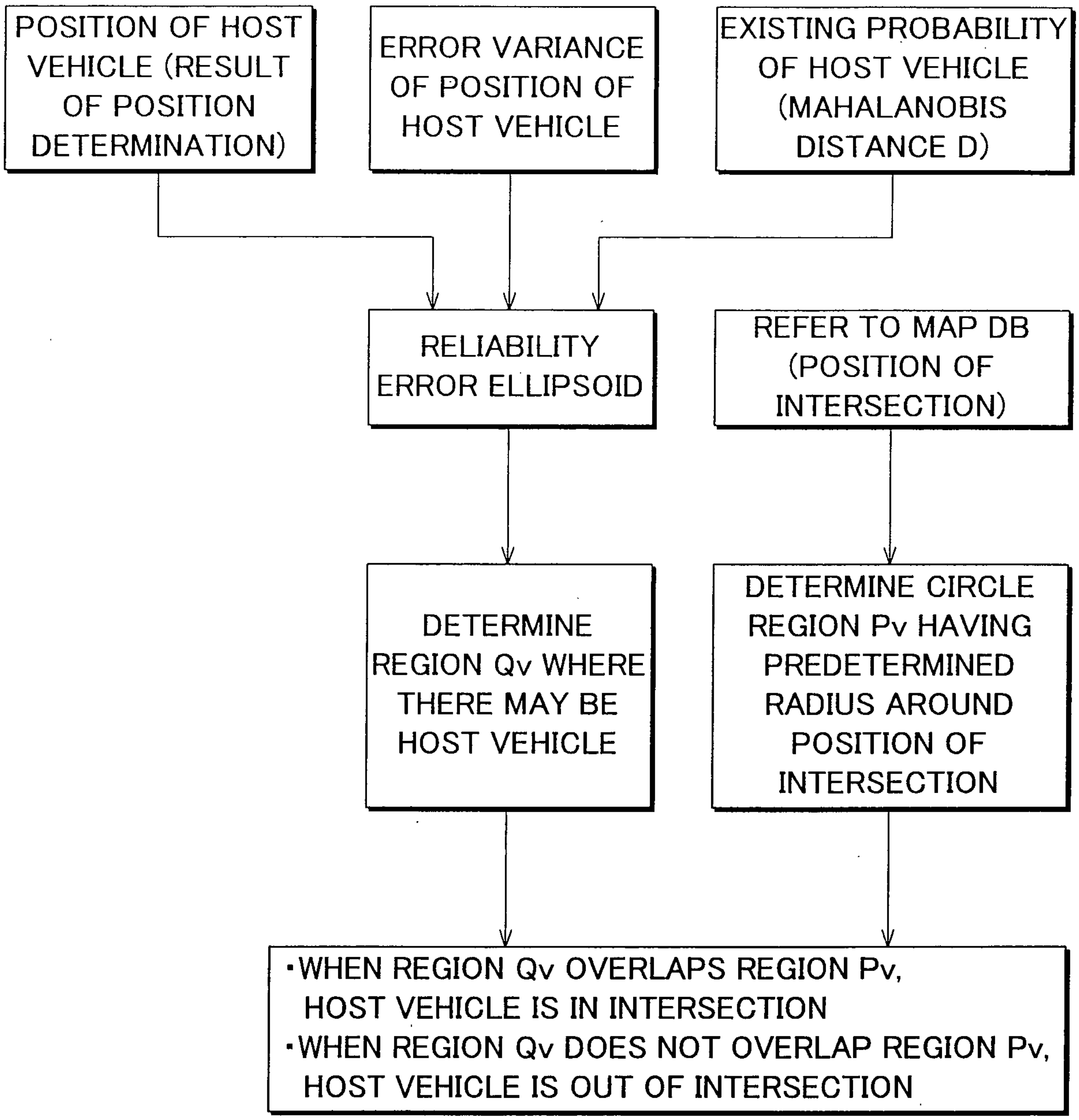
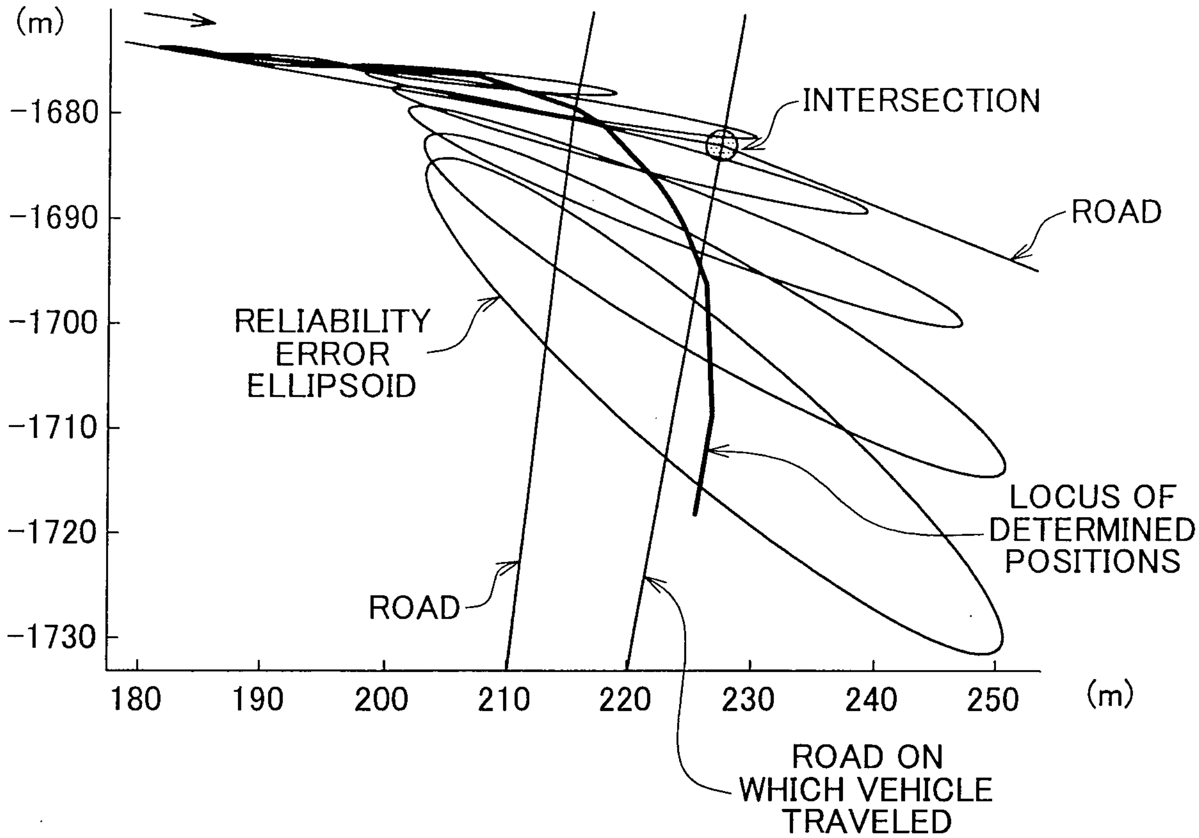

POSITION OF HOST VEHICLE (RESULT OF POSITION DETERMINATION)
ERROR VARIANCE OF POSITION OF HOST VEHICLE
EXISTING PROBABILITY OF HOST VEHICLE (MAHALANOBIS DISTANCE D)
RELIABILITY ERROR ELLIPSOID
REFER TO MAP DB (POSITION OF INTERSECTION)
DETERMINE REGION Qv WHERE THERE MAY BE HOST VEHICLE
DETERMINE CIRCLE REGION Pv HAVING PREDETERMINED RADIUS AROUND POSITION OF INTERSECTION
・WHEN REGION Qv OVERLAPS REGION Pv, HOST VEHICLE IS IN INTERSECTION
・WHEN REGION Qv DOES NOT OVERLAP REGION Pv, HOST VEHICLE IS OUT OF INTERSECTION

FIG. 6


(m)
-1680
-1690
-1700
-1710
-1720
-1730
180
190
200
210
220
230
240
250
(m)
INTERSECTION
ROAD
RELIABILITY
ERROR
ELLIPSOID
LOCUS OF
DETERMINED
POSITIONS
ROAD
ROAD ON
WHICH VEHICLE
TRAVELED