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(54) **POSITIONING DEVICE, METHOD OF CONTROLLING POSITIONING DEVICE, AND RECORDING MEDIUM**

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(57) **ABSTRACT**

A positioning device includes an estimated height storage section which stores an estimated height H1, a signal reception section which receives a satellite signal which is a signal from a satellite positioning system (SPS) satellite, a two-dimensional height calculation section which calculates a two-dimensional height H2*c* by two-dimensional positioning using the estimated height H1, a three-dimensional height calculation section which calculates a three-dimensional height H2*b* by preliminary three-dimensional positioning during two-dimensional positioning, a height selection section which selects the two-dimensional height H2*b* or the three-dimensional height H2*c* in order to update the estimated height H1, and an updating section which updates the estimated height H1 with the two-dimensional height H2*b* or the three-dimensional height H2*c* selected by the height selection section.

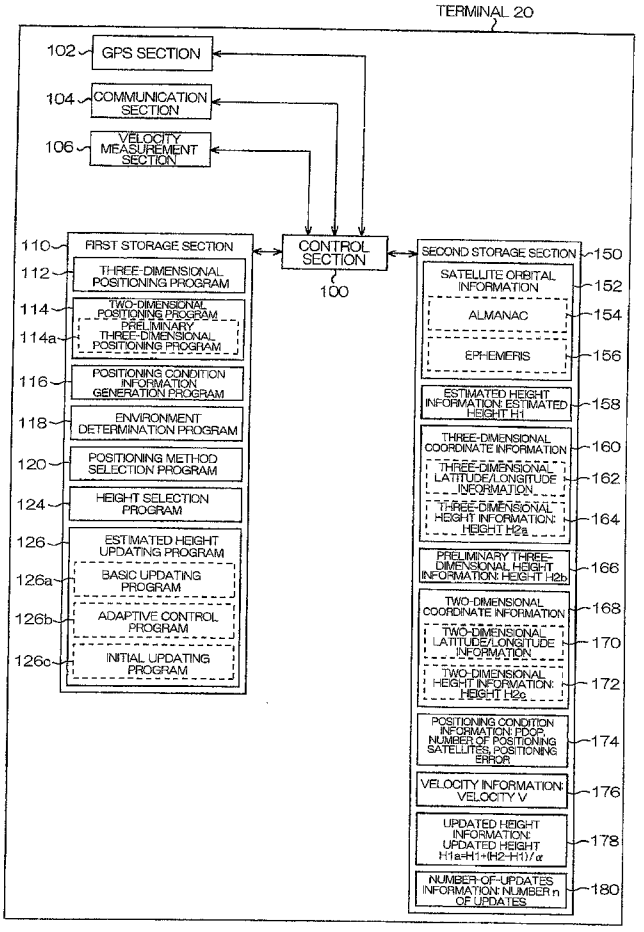


FIG. 1

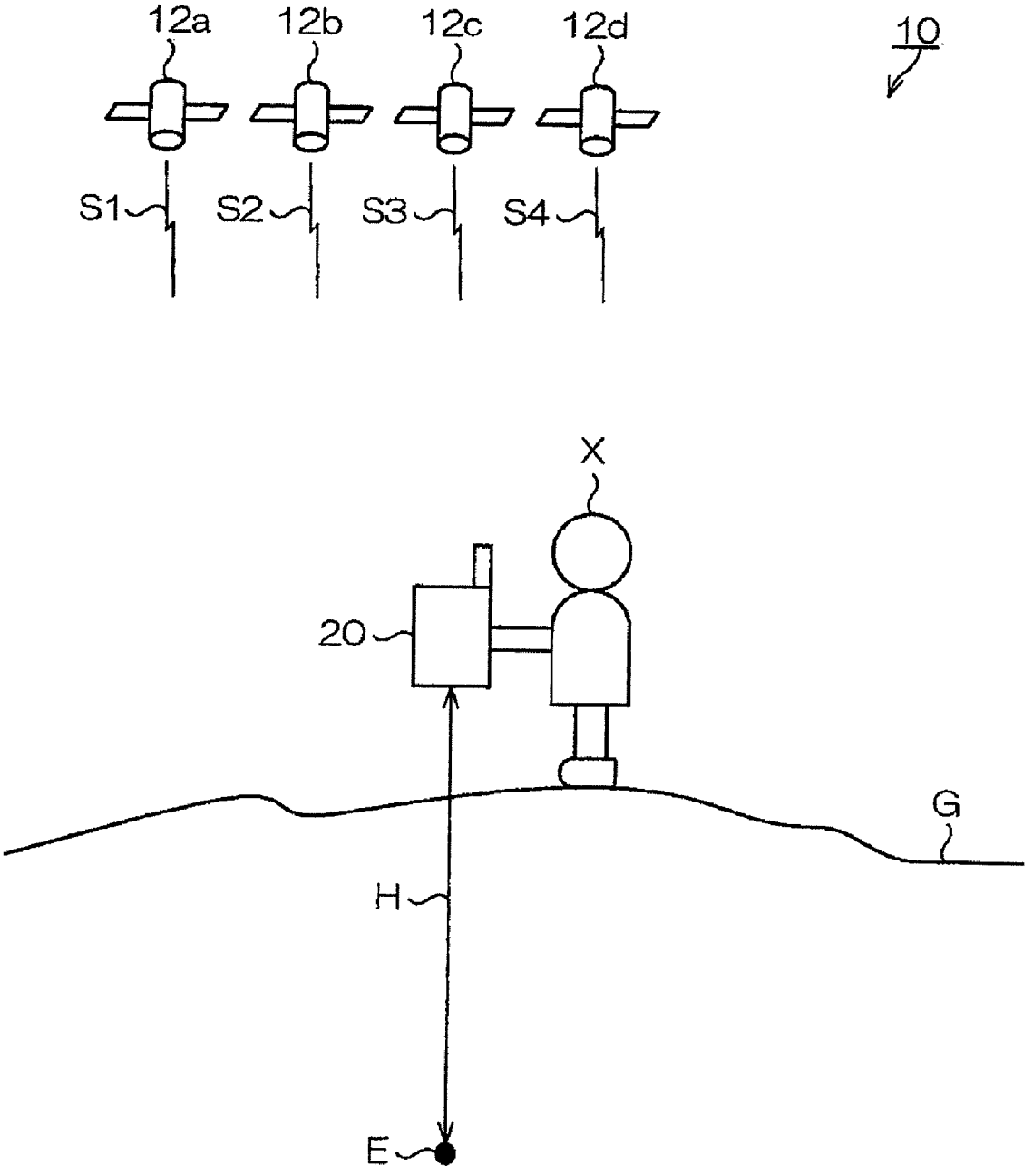


FIG. 2

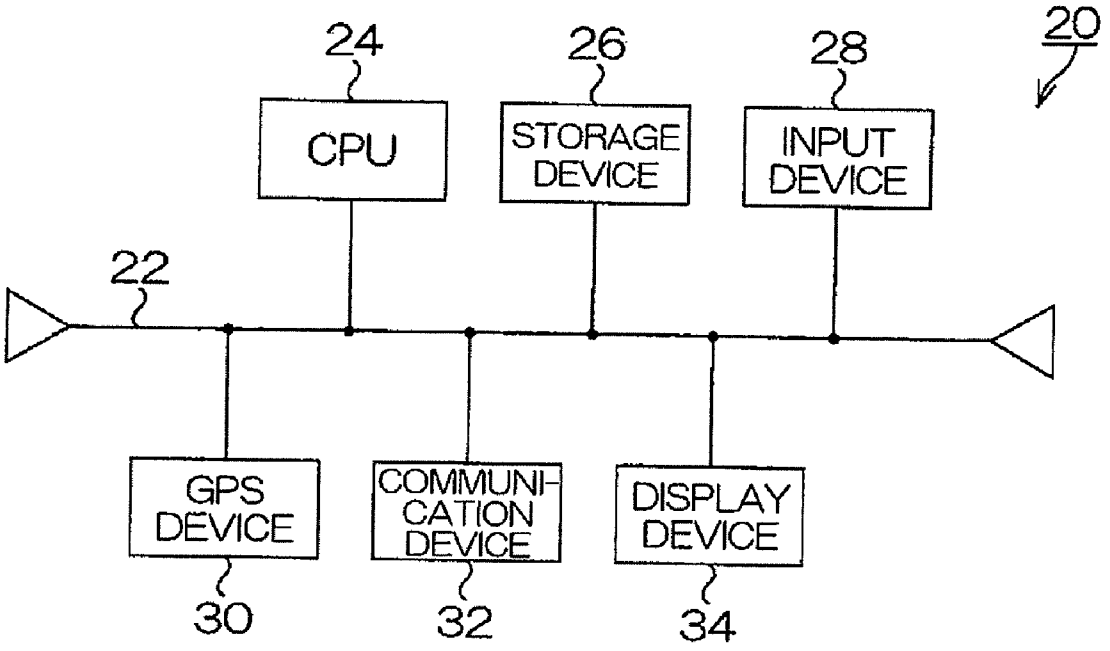

20
24
26
28
CPU
STORAGE DEVICE
INPUT DEVICE
22
GPS DEVICE
COMMUNI-CATION DEVICE
DISPLAY DEVICE
30
32
34

FIG. 3

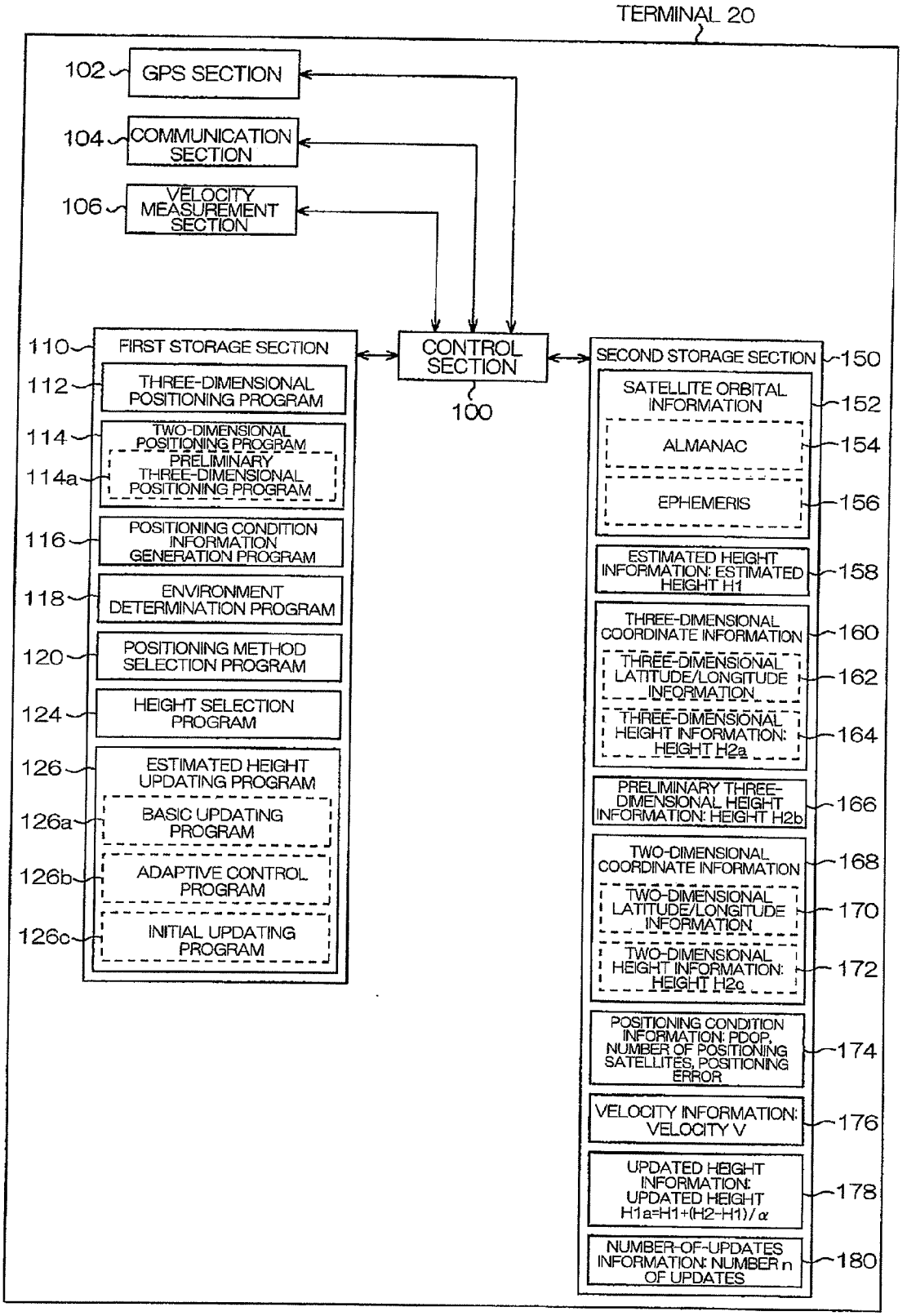

TERMINAL 20
102 GPS SECTION
104 COMMUNICATION SECTION
106 VELOCITY MEASUREMENT SECTION
CONTROL SECTION
100
110 FIRST STORAGE SECTION
112 THREE-DIMENSIONAL POSITIONING PROGRAM
114 TWO-DIMENSIONAL POSITIONING PROGRAM
114a PRELIMINARY THREE-DIMENSIONAL POSITIONING PROGRAM
116 POSITIONING CONDITION INFORMATION GENERATION PROGRAM
118 ENVIRONMENT DETERMINATION PROGRAM
120 POSITIONING METHOD SELECTION PROGRAM
124 HEIGHT SELECTION PROGRAM
126 ESTIMATED HEIGHT UPDATING PROGRAM
126a BASIC UPDATING PROGRAM
126b ADAPTIVE CONTROL PROGRAM
126c INITIAL UPDATING PROGRAM
SECOND STORAGE SECTION 150
SATELLITE ORBITAL INFORMATION 152
ALMANAC 154
EPHEMERIS 156
ESTIMATED HEIGHT INFORMATION: ESTIMATED HEIGHT H1 158
THREE-DIMENSIONAL COORDINATE INFORMATION 160
THREE-DIMENSIONAL LATITUDE/LONGITUDE INFORMATION 162
THREE-DIMENSIONAL HEIGHT INFORMATION: HEIGHT H2a 164
PRELIMINARY THREE-DIMENSIONAL HEIGHT INFORMATION: HEIGHT H2b 166
TWO-DIMENSIONAL COORDINATE INFORMATION 168
TWO-DIMENSIONAL LATITUDE/LONGITUDE INFORMATION 170
TWO-DIMENSIONAL HEIGHT INFORMATION: HEIGHT H2c 172
POSITIONING CONDITION INFORMATION: PDOP, NUMBER OF POSITIONING SATELLITES, POSITIONING ERROR 174
VELOCITY INFORMATION: VELOCITY V 176
UPDATED HEIGHT INFORMATION: UPDATED HEIGHT H1a=H1+(H2-H1)/α 178
NUMBER-OF-UPDATES INFORMATION: NUMBER n OF UPDATES 180

FIG. 4

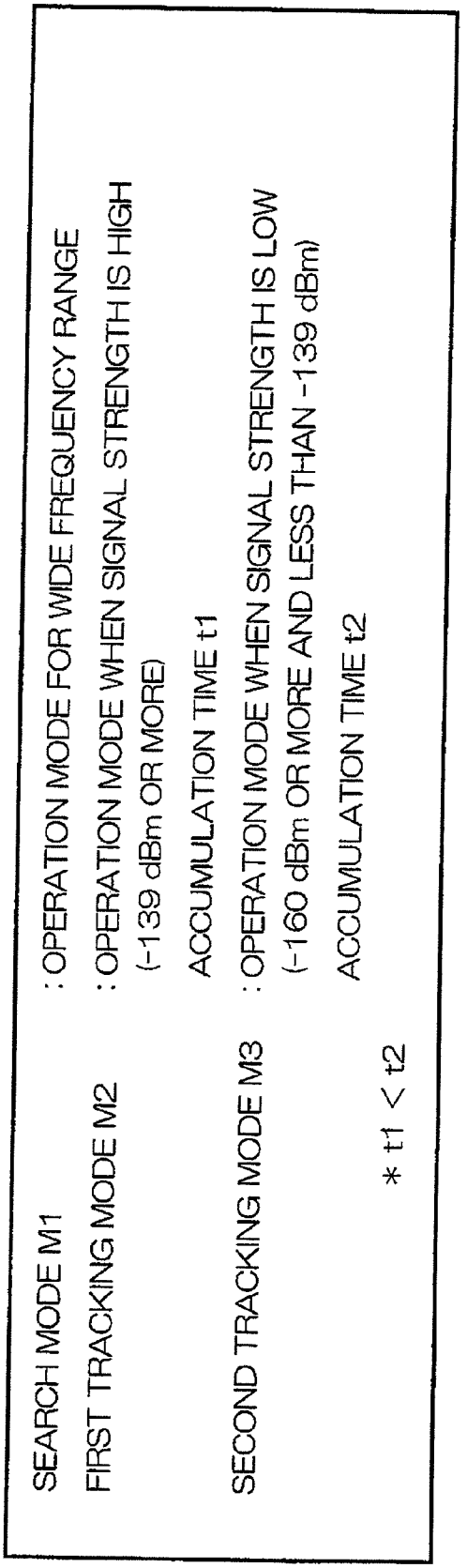

SEARCH MODE M1
: OPERATION MODE FOR WIDE FREQUENCY RANGE
FIRST TRACKING MODE M2
: OPERATION MODE WHEN SIGNAL STRENGTH IS HIGH
(-139 dBm OR MORE)
ACCUMULATION TIME t1
SECOND TRACKING MODE M3
: OPERATION MODE WHEN SIGNAL STRENGTH IS LOW
(-160 dBm OR MORE AND LESS THAN -139 dBm)
ACCUMULATION TIME t2
* t1 < t2

FIG. 5

STRONG ELECTRIC FIELD	FIRST STRONG ELECTRIC FIELD: a1 OR MORE AND LESS THAN a2 SECOND STRONG ELECTRIC FIELD: a2 OR MORE AND LESS THAN a3 THIRD STRONG ELECTRIC FIELD: a3 OR MORE $a1 < a2 < a3$
WEAK ELECTRIC FIELD	FIRST WEAK ELECTRIC FIELD: b1 OR MORE AND LESS THAN b2 SECOND WEAK ELECTRIC FIELD: b2 OR MORE AND LESS THAN b3 $b1 < b2 < b3$

FIG. 6

ENVIRONMENT DETERMINATION PROGRAM 118	POSITIONING SPECIFICATION
FIRST ENVIRONMENT (OPEN SKY): M2 SATELLITE WITH THIRD STRONG ELECTRIC FIELD IS 8 OR MORE AND ALL	POSITIONS USING ALL MEASUREMENT
SECOND ENVIRONMENT (QUASI-OPEN SKY): M2 SATELLITE WITH THIRD STRONG ELECTRIC FIELD, M2 SATELLITE WITH SECOND STRONG ELECTRIC FIELD, M3 SATELLITE	POSITIONS EXCLUDING M3 SATELLITES MEASUREMENT
THIRD ENVIRONMENT (FIRST MULTIPATH ENVIRONMENT): M2 SATELLITE WITH FIRST STRONG ELECTRIC FIELD, M2 SATELLITE WITH SECOND STRONG ELECTRIC FIELD, M3 SATELLITE	POSITIONS WITH MULTIPATH MEASUREMENT
FORTH ENVIRONMENT (BIASED): M2 SATELLITE WITH THIRD STRONG ELECTRIC FIELD, M3 SATELLITE WITH SECOND WEAK ELECTRIC FIELD, BIASED PDOP	POSITIONS EXCLUDING BIAS AND OPPOSITE DIRECTION SATELLITE MEASUREMENT
FIFTH ENVIRONMENT (VALLEY): M2 SATELLITE WITH THIRD STRONG ELECTRIC FIELD, M3 SATELLITE WITH SECOND WEAK ELECTRIC FIELD, NO BIASED PDOP	POSITIONS EXCLUDING OBSTACLE DIRECTION MEASUREMENT AND M3 SATELLITE WITH SECOND WEAK ELECTRIC FIELD
SIXTH ENVIRONMENT (SECOND MULTIPATH): M3 SATELLITES LARGER THAN M2 SATELLITES	POSITIONS WITH MULTIPATH MEASUREMENT (INCLUDING M2 SATELLITE MEASUREMENT)
SEVENTH ENVIRONMENT (THIRD MULTIPATH): ONE M2 SATELLITE AND M3 SATELLITES	POSITIONS WITH MULTIPATH MEASUREMENT (CORRECTS MEASUREMENT ACCURACY)
EIGHTH ENVIRONMENT (SECOND WEAK ELECTRIC FIELD): ONLY M3 SATELLITES WITH SECOND WEAK ELECTRIC FIELD	POSITIONS USING ALL MEASUREMENTS
NINTH ENVIRONMENT (FIRST WEAK ELECTRIC FIELD): ONLY M3 SATELLITES WITH FIRST WEAK ELECTRIC FIELD	POSITIONS WITH INCREASED CUMULATIVE TIME

FIG. 7A

GAIN COUNTER	0	1	2	3	4	5	6	7	8	9
GAIN	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5

FIG. 7B

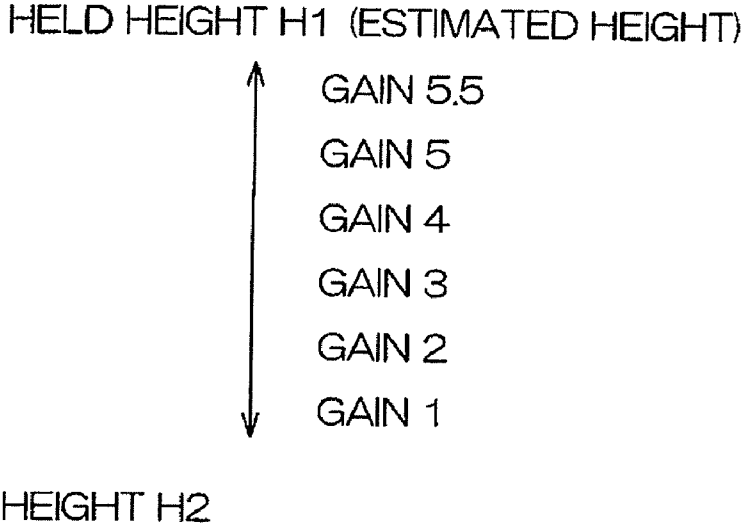


FIG. 7C

GAIN COUNTER	0	1	2	3	4	5	6	7	8	9
GAIN	1	1	2	2	3	3	4	4	5	5

FIG. 8

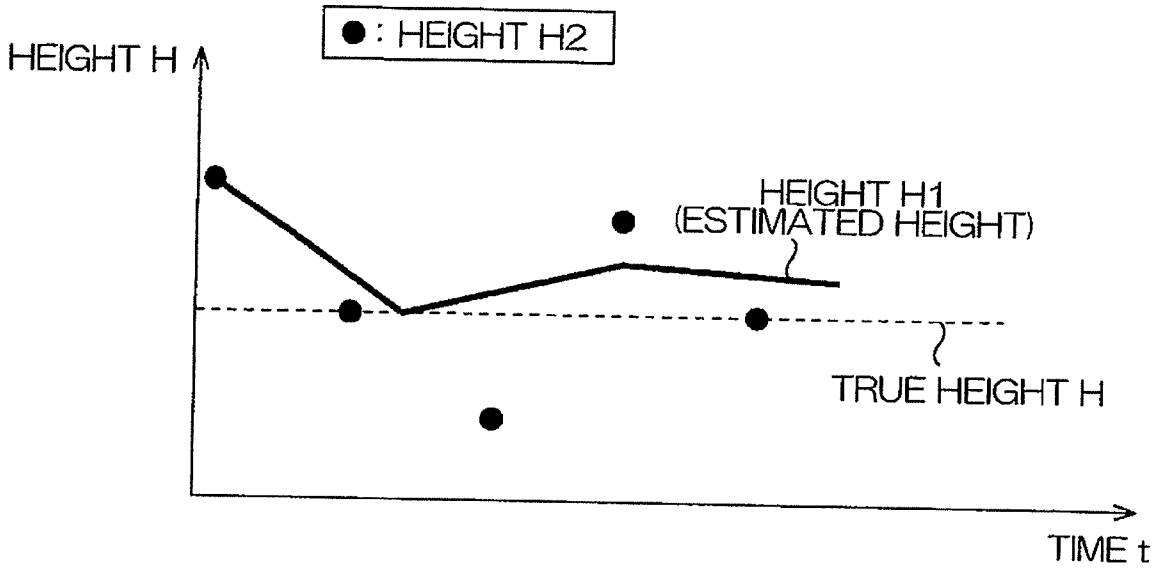

● : HEIGHT H2
HEIGHT H
HEIGHT H1
(ESTIMATED HEIGHT)
TRUE HEIGHT H
TIME t

FIG. 9

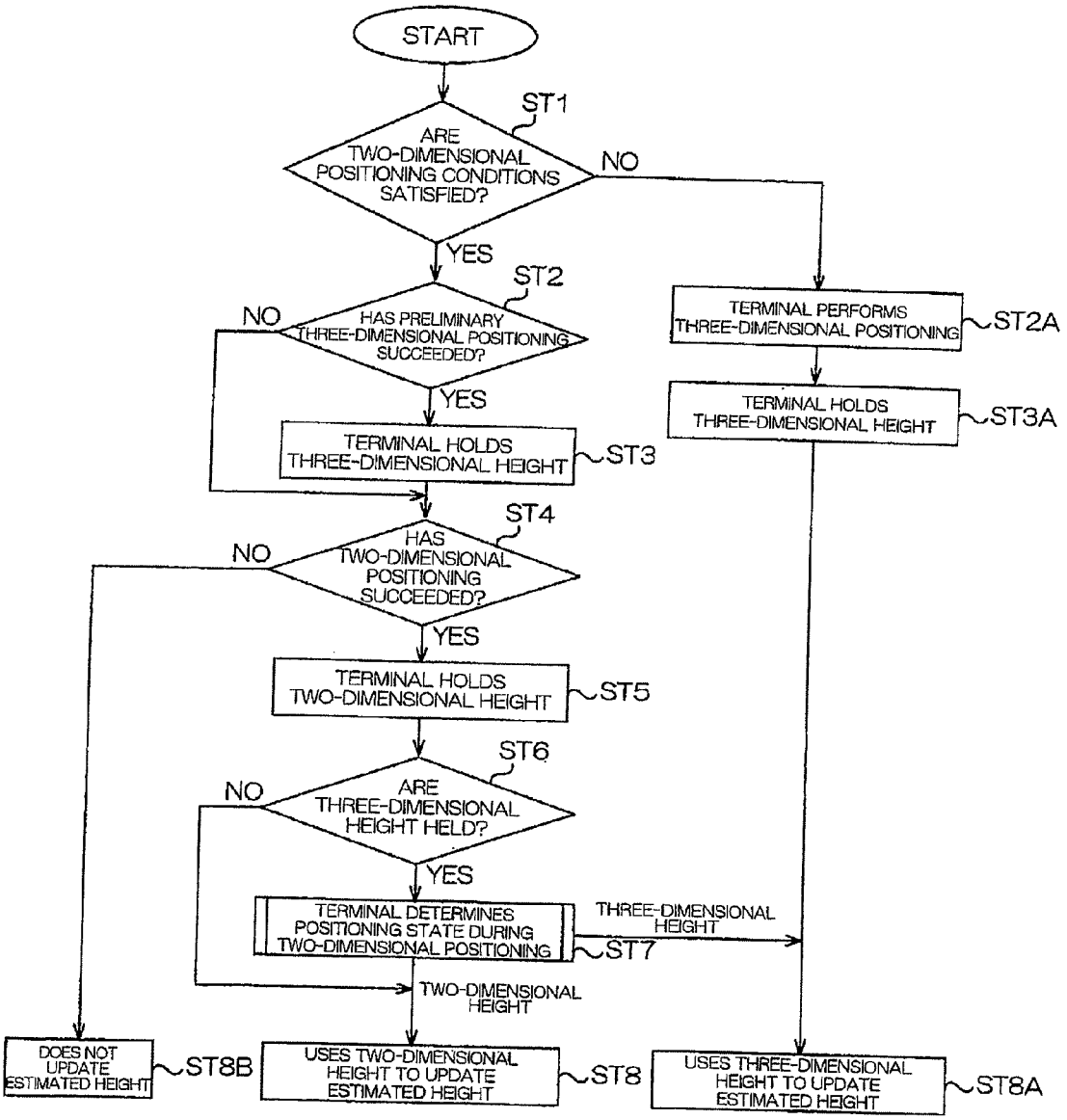

START
ST1
ARE TWO-DIMENSIONAL POSITIONING CONDITIONS SATISFIED?
NO
YES
ST2
HAS PRELIMINARY THREE-DIMENSIONAL POSITIONING SUCCEEDED?
NO
YES
TERMINAL HOLDS THREE-DIMENSIONAL HEIGHT
ST3
TERMINAL PERFORMS THREE-DIMENSIONAL POSITIONING
ST2A
TERMINAL HOLDS THREE-DIMENSIONAL HEIGHT
ST3A
ST4
HAS TWO-DIMENSIONAL POSITIONING SUCCEEDED?
NO
YES
TERMINAL HOLDS TWO-DIMENSIONAL HEIGHT
ST5
ST6
ARE THREE-DIMENSIONAL HEIGHT HELD?
NO
YES
TERMINAL DETERMINES POSITIONING STATE DURING TWO-DIMENSIONAL POSITIONING
ST7
THREE-DIMENSIONAL HEIGHT
TWO-DIMENSIONAL HEIGHT
DOES NOT UPDATE ESTIMATED HEIGHT
ST8B
USES TWO-DIMENSIONAL HEIGHT TO UPDATE ESTIMATED HEIGHT
ST8
USES THREE-DIMENSIONAL HEIGHT TO UPDATE ESTIMATED HEIGHT
ST8A

FIG. 10

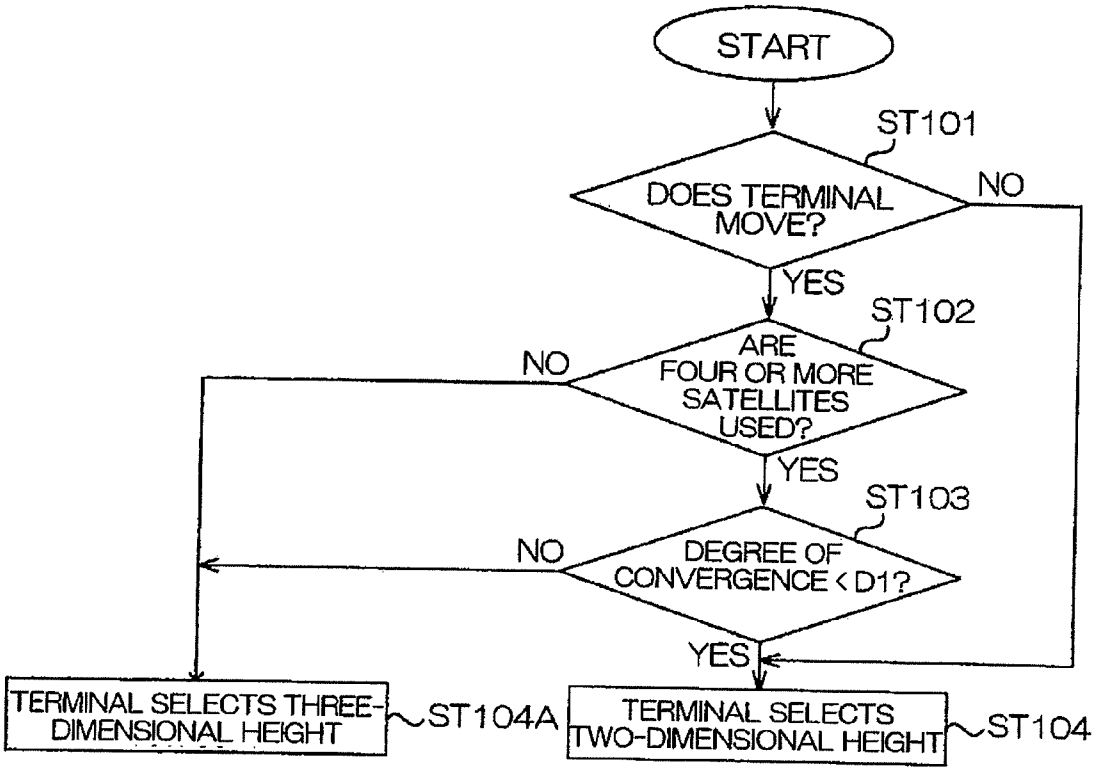

START
ST101
DOES TERMINAL MOVE?
NO
YES
ST102
ARE FOUR OR MORE SATELLITES USED?
NO
YES
ST103
DEGREE OF CONVERGENCE < D1?
NO
YES
TERMINAL SELECTS THREE-DIMENSIONAL HEIGHT
ST104A
TERMINAL SELECTS TWO-DIMENSIONAL HEIGHT
ST104

FIG. 11

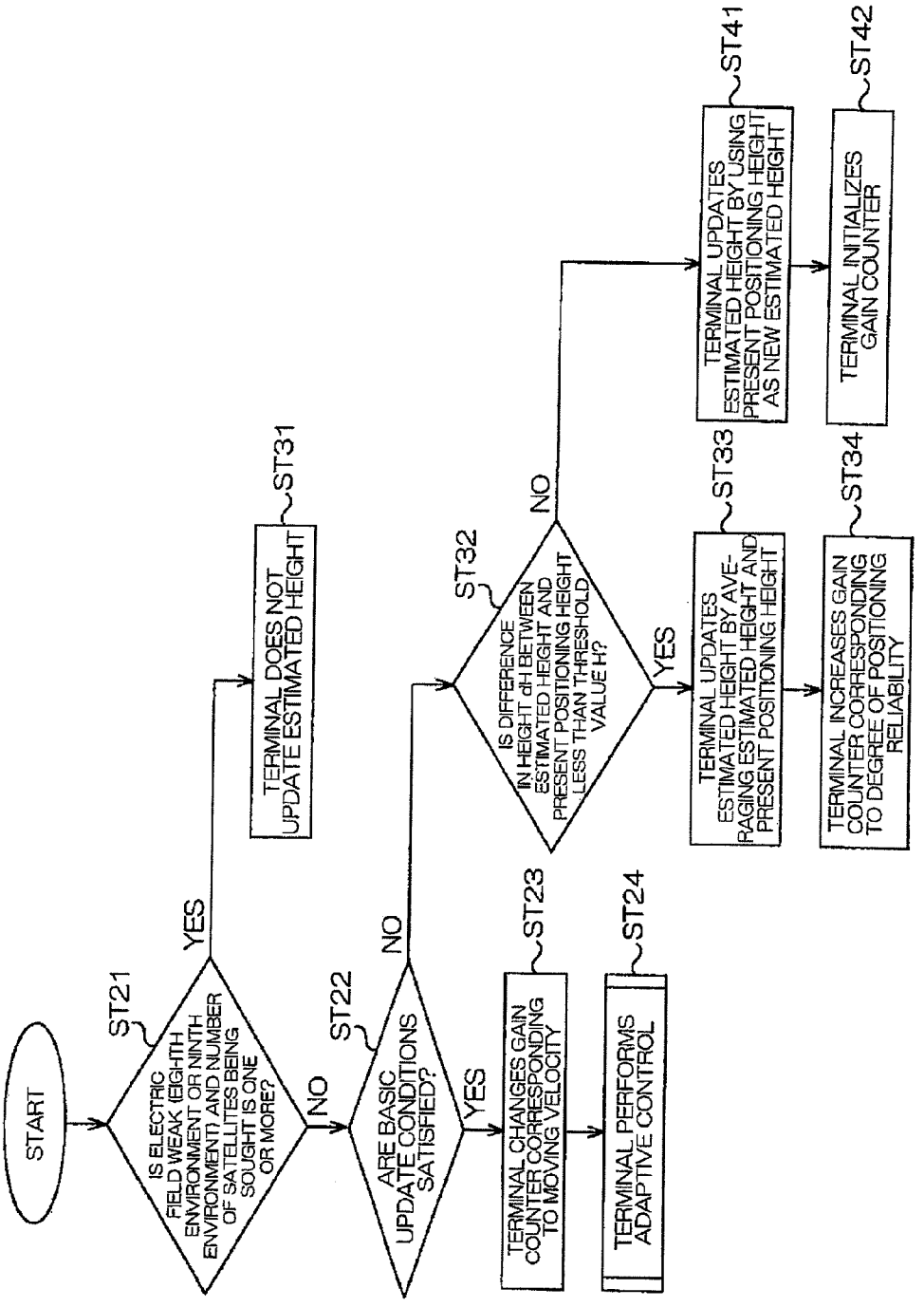
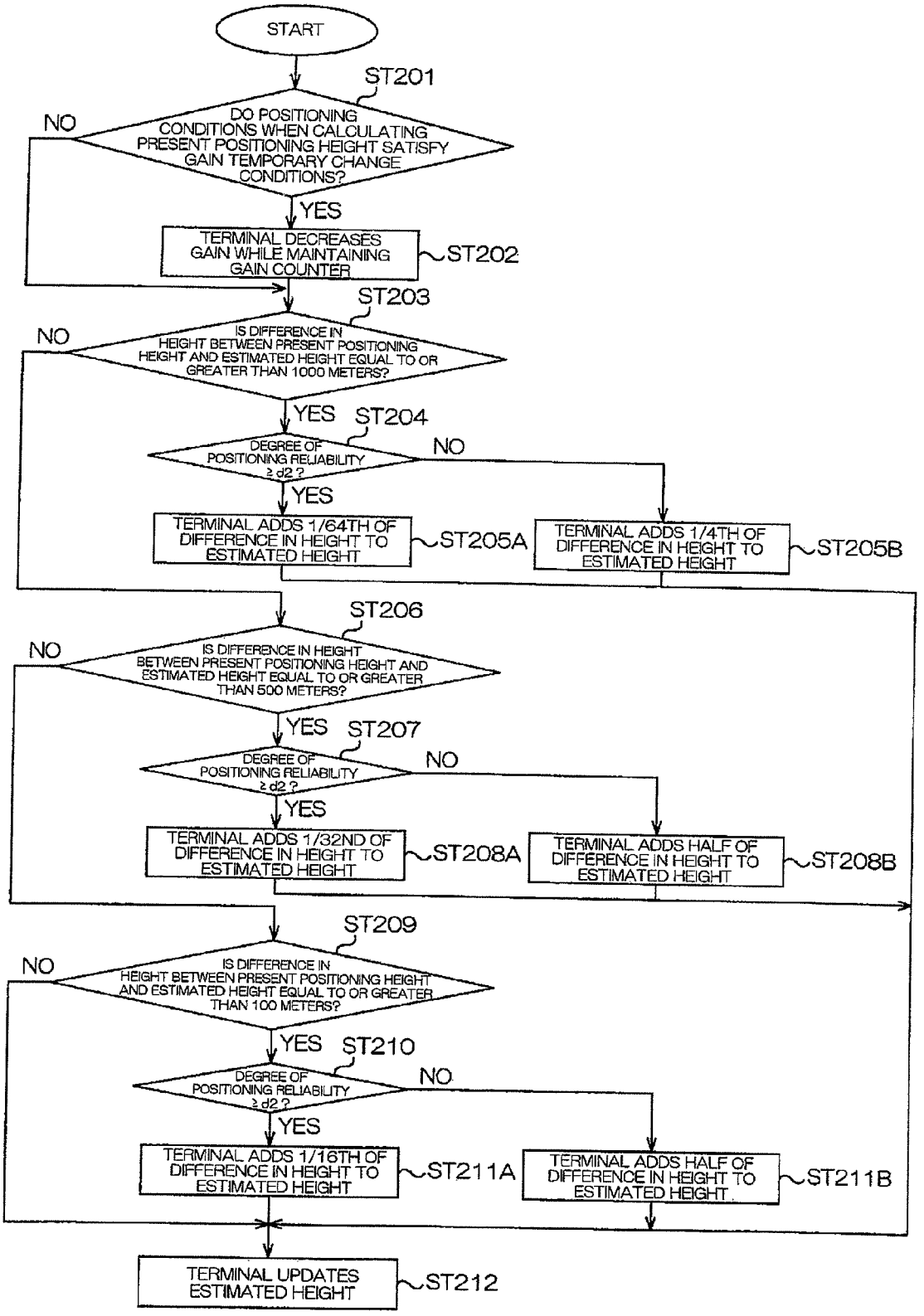

START
ST21
IS ELECTRIC FIELD WEAK (EIGHTH ENVIRONMENT OR NINTH ENVIRONMENT) AND NUMBER OF SATELLITES BEING SOUGHT IS ONE OR MORE?
YES
TERMINAL DOES NOT UPDATE ESTIMATED HEIGHT
ST31
NO
ST22
ARE BASIC UPDATE CONDITIONS SATISFIED?
NO
ST32
IS DIFFERENCE IN HEIGHT dH BETWEEN ESTIMATED HEIGHT AND PRESENT POSITIONING HEIGHT LESS THAN THRESHOLD VALUE H?
NO
ST41
TERMINAL UPDATES ESTIMATED HEIGHT BY USING PRESENT POSITIONING HEIGHT AS NEW ESTIMATED HEIGHT
ST42
TERMINAL INITIALIZES GAIN COUNTER
YES
ST33
TERMINAL UPDATES ESTIMATED HEIGHT BY AVERAGING ESTIMATED HEIGHT AND PRESENT POSITIONING HEIGHT
ST34
TERMINAL INCREASES GAIN COUNTER CORRESPONDING TO DEGREE OF POSITIONING RELIABILITY
YES
ST23
TERMINAL CHANGES GAIN COUNTER CORRESPONDING TO MOVING VELOCITY
ST24
TERMINAL PERFORMS ADAPTIVE CONTROL

FIG. 12


START
ST201
DO POSITIONING CONDITIONS WHEN CALCULATING PRESENT POSITIONING HEIGHT SATISFY GAIN TEMPORARY CHANGE CONDITIONS?
NO
YES
TERMINAL DECREASES GAIN WHILE MAINTAINING GAIN COUNTER
ST202
ST203
IS DIFFERENCE IN HEIGHT BETWEEN PRESENT POSITIONING HEIGHT AND ESTIMATED HEIGHT EQUAL TO OR GREATER THAN 1000 METERS?
NO
YES
ST204
DEGREE OF POSITIONING RELIABILITY ≥ d2 ?
NO
YES
TERMINAL ADDS 1/64TH OF DIFFERENCE IN HEIGHT TO ESTIMATED HEIGHT
ST205A
TERMINAL ADDS 1/4TH OF DIFFERENCE IN HEIGHT TO ESTIMATED HEIGHT
ST205B
ST206
IS DIFFERENCE IN HEIGHT BETWEEN PRESENT POSITIONING HEIGHT AND ESTIMATED HEIGHT EQUAL TO OR GREATER THAN 500 METERS?
NO
YES
ST207
DEGREE OF POSITIONING RELIABILITY ≥ d2 ?
NO
YES
TERMINAL ADDS 1/32ND OF DIFFERENCE IN HEIGHT TO ESTIMATED HEIGHT
ST208A
TERMINAL ADDS HALF OF DIFFERENCE IN HEIGHT TO ESTIMATED HEIGHT
ST208B
ST209
IS DIFFERENCE IN HEIGHT BETWEEN PRESENT POSITIONING HEIGHT AND ESTIMATED HEIGHT EQUAL TO OR GREATER THAN 100 METERS?
NO
YES
ST210
DEGREE OF POSITIONING RELIABILITY ≥ d2 ?
NO
YES
TERMINAL ADDS 1/16TH OF DIFFERENCE IN HEIGHT TO ESTIMATED HEIGHT
ST211A
TERMINAL ADDS HALF OF DIFFERENCE IN HEIGHT TO ESTIMATED HEIGHT
ST211B
TERMINAL UPDATES ESTIMATED HEIGHT
ST212

POSITIONING DEVICE, METHOD OF CONTROLLING POSITIONING DEVICE, AND RECORDING MEDIUM

[0001] This application claims priority to U.S. patent application Ser. No. 11/882,734 and Japanese Patent Application No. 2006-228770. The entire disclosures of U.S. patent application Ser. No. 11/882,734 and Japanese Patent Application No. 2006-228770 are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to a positioning device which utilizes signals from positioning satellites, a method of controlling a positioning device, and a recording medium.

[0003] A positioning system has been used in practice which locates the present position of a GPS receiver utilizing a satellite positioning system (SPS) such as a global positioning system (GPS).

[0004] The GPS receiver receives signals from GPS satellites and calculates the distance between each GPS satellite and the GPS receiver (hereinafter called "pseudo-range") based on the difference between the time at which the signal is transmitted from each GPS satellite and the time at which the signal reaches the GPS receiver (hereinafter called "delay time"). The GPS receiver calculates (locates) the present position using the pseudo-range and satellite orbital information of each GPS satellite contained in the signal received from each GPS satellite.

[0005] When the GPS receiver can receive signals from four or more GPS satellites, the GPS receiver can perform three-dimensional positioning which calculates the latitude, the longitude, and the height of the present position.

[0006] When the GPS receiver can receive signals from three GPS satellites, the GPS receiver can perform two-dimensional positioning which calculates the latitude and the longitude of the present position. For example, the GPS receiver regards the center of the earth as one GPS satellite, and uses the distance between the center of the earth and the present position as the pseudo-range. The GPS receiver then calculates (locates) the position in the same manner as in three-dimensional positioning. Therefore, the GPS receiver must hold the height information of the present position in advance when performing two-dimensional positioning.

[0007] A two-dimensional positioning technology using the height acquired from map data (e.g. JP-A-2002-341012) and a two-dimensional positioning technology using the height calculated during the preceding positioning using a set of GPS satellites with the minimum vertical dilution of precision (VDOP) or the height calculated during the preceding three-dimensional positioning (e.g. JP-B-6-75103) have been proposed.

[0008] However, the load imposed on storage means is increased when holding the map data. Moreover, the height information obtained from the map data may have a large error.

[0009] When using the height calculated during the preceding positioning using a set of GPS satellites with the minimum VDOP, the height may have a large error due to poor positioning conditions (e.g. environment in which the signal strength is weak or environment in which multipaths occur to a large extent) during the preceding positioning. When using the height calculated during the preceding three-dimensional positioning, the height may also have a large error due to poor positioning conditions during the preceding positioning

[0010] The applicant of the invention has filed a patent application regarding technology of updating the height information taking the conditions during the preceding positioning into consideration (Japanese Patent Application No. 2005-151048 (published as JP-A-2006-329705)). However, since this technology updates the height information when the three-dimensional height information has specific reliability, the height information cannot be updated when the three-dimensional height information has low reliability (e.g. multipath environment). This poses a problem in which the height information may not be promptly updated.

SUMMARY

[0011] According to one aspect of the invention, there is provided a positioning device comprising:

[0012] an estimated height storage section which stores an estimated height;

[0013] a signal reception section which receives a satellite signal which is a signal from a satellite positioning system (SPS) satellite;

[0014] a two-dimensional height calculation section which calculates a height of a present position as a two-dimensional height by performing two-dimensional positioning which locates the present position based on the received satellite signals using the estimated height as a distance from the center of the earth;

[0015] a three-dimensional height calculation section which calculates the height of the present position as a three-dimensional height by performing preliminary three-dimensional positioning which preliminarily locates the present position based on the received satellite signals without using the estimated height when performing the two-dimensional positioning;

[0016] a height selection section which selects the two-dimensional height or the three-dimensional height for updating the estimated height stored in the estimated height storage section; and

[0017] an updating section which updates the estimated height stored in the estimated height storage section using the two-dimensional height or the three-dimensional height selected by the height selection section.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0018] FIG. **1** is a schematic view showing a positioning system according to one embodiment of the invention.

[0019] FIG. **2** is a schematic view showing the main hardware configuration of a terminal.

[0020] FIG. **3** is a schematic view showing the main software configuration of the terminal.

[0021] FIG. **4** is a view showing an example of the operation mode of the terminal.

[0022] FIG. **5** is a view illustrative of a process based on an environment determination program.

[0023] FIG. **6** is a view illustrative of a process based on the environment determination program.

[0024] FIGS. **7**A to **7**C are views illustrative of a process based on a basic updating program.

[0025] FIG. **8** is a view showing an example of a state in which height information is updated.

[0026] FIG. **9** is a schematic flowchart showing an operation example of the positioning system.

[0027] FIG. **10** is a schematic flowchart showing an operation example of the positioning system.

[0028] FIG. **11** is a schematic flowchart showing an operation example of the positioning system.

[0029] FIG. **12** is a schematic flowchart showing an operation example of the positioning system.

DETAILED DESCRIPTION OF THE EMBODIMENT

[0030] The invention may allow a reduction in load imposed on the storage for holding the height data, ensures acquisition of accurate height information used for two-dimensional positioning while reducing the effects of poor positioning conditions during the preceding positioning, and allows the height information to be promptly updated.

[0031] According to one embodiment of the invention, there is provided a positioning device comprising:

[0032] an estimated height storage section which stores an estimated height;

[0033] a signal reception section which receives a satellite signal which is a signal from a satellite positioning system (SPS) satellite;

[0034] a two-dimensional height calculation section which calculates a height of a present position as a two-dimensional height by performing two-dimensional positioning which locates the present position based on the received satellite signals using the estimated height as a distance from the center of the earth;

[0035] a three-dimensional height calculation section which calculates the height of the present position as a three-dimensional height by performing preliminary three-dimensional positioning which preliminarily locates the present position based on the received satellite signals without using the estimated height when performing the two-dimensional positioning;

[0036] a height selection section which selects the two-dimensional height or the three-dimensional height for updating the estimated height stored in the estimated height storage section; and

[0037] an updating section which updates the estimated height stored in the estimated height storage section using the two-dimensional height or the three-dimensional height selected by the height selection section.

[0038] According to the above embodiment, since the positioning device includes the two-dimensional height calculation section, the two-dimensional height can be calculated. Therefore, the positioning device can calculate the height even when three-dimensional positioning cannot be performed or the reliability of the positioning results obtained by three-dimensional positioning is insufficient (hereinafter called "when three-dimensional positioning is not appropriate").

[0039] Since the positioning device includes the three-dimensional height calculation section, the three-dimensional height can be calculated by performing preliminary three-dimensional positioning during two-dimensional positioning. There may be a case where three-dimensional positioning is possible even if three-dimensional positioning is not appropriate. The three-dimensional height may be appropriate for updating the estimated height even if two-dimensional positioning is appropriate for calculating the located position. Therefore, the positioning device calculates the two-dimensional height and the three-dimensional height. This increases the degrees of freedom of selection of the height for updating the estimated height.

[0040] The term "two-dimensional positioning" used herein means calculating the height in addition to the latitude and the longitude. The term "two-dimensional positioning" used herein refers to one type of three-dimensional positioning which calculating the latitude, the longitude, and the height. In three-dimensional positioning, the position is located using the positions of four or more satellites in the orbits and the pseudo-range between each satellite and the positioning device. In two-dimensional positioning, the center of the earth is regarded as one satellite and used for positioning. Specifically, two-dimensional positioning locates the position on the assumption that the estimated height is the pseudo-range between the center of the earth and the positioning device. Therefore, two-dimensional positioning exhibits higher positioning accuracy when the estimated height has high accuracy.

[0041] However, since it is considered that the true height changes in a reception state such as a state in which the positioning device moves at a velocity equal to or higher than a specific velocity, three-dimensional positioning which does not use the estimated height ensures excellent followability to the true movement state to exhibit high positioning accuracy.

[0042] Therefore, even if the estimated height has high accuracy, three-dimensional positioning exhibits high accuracy in comparison with two-dimensional positioning depending on the reception state.

[0043] Since the positioning device includes the height selection section, the positioning device can select the two-dimensional height or the three-dimensional height in order to update the estimated height depending on the reception state during two-dimensional positioning.

[0044] Since the positioning device includes the updating section, the positioning device can update the estimated height using the two-dimensional height or the three-dimensional height. Specifically, even if three-dimensional positioning is not appropriate, the positioning device can update the estimated height using the two-dimensional height or the three-dimensional height. Therefore, the positioning device can promptly update the estimated height.

[0045] Since the two-dimensional height and the three-dimensional height are new information generated by positioning, the estimated height which has been held is corrected by new information by updating the estimated height with the two-dimensional height or the three-dimensional height. This enables the estimated height to be made closer to the true height. Moreover, since the positioning device can calculate the two-dimensional height and the three-dimensional height and select a more appropriate height, the estimated height can be further made closer to the true height.

[0046] The height close to the true height is called an accurate height. Information indicating the height close to the true height is called accurate height information.

[0047] Since the positioning device can hold and update only one estimated height using the updating section, the load imposed on the storage for holding height data is reduced.

[0048] Therefore, the positioning device allows accurate height information used for two-dimensional positioning to be acquired while reducing the storage load for holding height data and reducing the effects of poor positioning conditions during the preceding positioning, and allows the height information to be promptly updated.

[0049] The positioning device may comprise:

[0050] a three-dimensional positioning section which performs three-dimensional positioning which locates the present position based on the received satellite signals without using the estimated height;

[0051] a positioning environment determination section which determines a positioning environment when performing the two-dimensional positioning or the three-dimensional positioning; and

[0052] a positioning method selection section which selects the two-dimensional positioning or the three-dimensional positioning based on the positioning environment;

[0053] wherein the updating section may update the estimated height using the three-dimensional height calculated by the three-dimensional positioning when the three-dimensional positioning section has performed the three-dimensional positioning.

[0054] Since the three-dimensional height is calculated by preliminary three-dimensional positioning, the three-dimensional height is highly accurate in a good reception environment such as an open sky environment. On the other hand, the three-dimensional height has poor accuracy in a poor reception environment such as a multipath environment.

[0055] Since the two-dimensional height is calculated using the estimated height, the two-dimensional height is calculated in a state in which the effects of a poor reception environment are reduced. Therefore, the two-dimensional height exhibits high accuracy in comparison with the three-dimensional height in a poor reception environment.

[0056] According to above embodiment, since the positioning device can appropriately select two-dimensional positioning or three-dimensional positioning based on the positioning environment, the positioning device can calculate an accurate located position corresponding to the reception environment.

[0057] Since the height included in the accurate located position has high accuracy, the estimated height can be made closer to the true height by updating the estimated height using the three-dimensional height calculated by three-dimensional positioning.

[0058] In the positioning device, the height selection section may select the two-dimensional height or the three-dimensional height based on a movement state of the positioning device and reliability of positioning information calculated in the two-dimensional positioning.

[0059] Even if the positioning device moves, the two-dimensional height exhibits high accuracy in comparison with the three-dimensional height when the reliability of the positioning information calculated by two-dimensional positioning is sufficient.

[0060] According to above embodiment, the height selection section can select the two-dimensional height or the three-dimensional height based on not only the movement state of the but also comparison between the reliability of the two-dimensional height and the reliability of the three-dimensional height.

[0061] The positioning device may comprise:

[0062] an estimated height evaluation section which determines whether or not the estimated height satisfies predetermined basic update conditions including at least a number of updates of the estimated height as a condition; and a difference-in-height calculation section which calculates a difference in height between the estimated height and the two-dimensional height or the three-dimensional height when the estimated height evaluation section has determined that the estimated height does not satisfy the basic update conditions;

[0063] wherein the updating section may update the estimated height by weighted averaging the two-dimensional height or the three-dimensional height selected by the height selection section and the estimated height stored in the estimated height storage section, and may update the estimated height while increasing weight of the estimated height when the difference in height is within a predetermined difference-in-height allowable range.

[0064] According to this configuration, the positioning device can update the estimated height even if the estimated height does not satisfy the basic update conditions.

[0065] It is considered that the estimated height is close to the true height when the difference in height is within a specific range. Specifically, the estimated height has high reliability. Therefore, the estimated height can be made close to the true height by updating the estimated height while increasing the weight of the estimated height.

[0066] According to above embodiment, since the updating section updates the estimated height while increasing the weight of the estimated height when the difference in height is within the difference-in-height allowable range, even if the basic update conditions are not satisfied, the estimated height can be made close to the true height.

[0067] In the positioning device, the updating section may update the estimated height while reducing the weight of the estimated height when the difference in height is not within the difference-in-height allowable range.

[0068] It is considered that the estimated height differ from the true height to a large extent when the difference in height is not within a specific range. Specifically, the estimated height has low reliability. Therefore, the estimated height can be made close to the true height by updating the estimated height while reducing the weight of the estimated height.

[0069] According to above embodiment, since the updating section updates the estimated height while reducing the weight of the estimated height when the difference in height is within the difference-in-height allowable range, even if the basic update conditions are not satisfied, the estimated height can be made close to the true height.

[0070] The positioning device may comprise: a gain table including a gain indicating the weight of the estimated height, and a gain counter for designating the gain.

[0071] According to this configuration, the updating section can change the gain by changing the gain counter.

[0072] In the positioning device, the updating section may update the estimated height based on the difference in height and a degree of positioning reliability.

[0073] According to another embodiment of the invention, there is provided a method of controlling a positioning device including an estimated height storage section which stores an estimated height and a signal reception section which receives a satellite signal which is a signal from a satellite positioning system (SPS) satellite, the method comprising:

[0074] calculating a height of a present position as a two-dimensional height by performing two-dimensional positioning which locates the present position based on the received satellite signals using the estimated height as a distance from the center of the earth;

[0075] calculating the height of the present position as a three-dimensional height by performing preliminary three-dimensional positioning which preliminarily locates the

present position based on the received satellite signals without using the estimated height when performing the two-dimensional positioning;

[0076] selecting the two-dimensional height or the three-dimensional height for updating the estimated height stored in the estimated height storage section; and

[0077] updating the estimated height stored in the estimated height storage section using selected one of the two-dimensional height and the three-dimensional height.

[0078] This allows accurate height information used for two-dimensional positioning to be acquired while reducing the storage load for holding height data and reducing the effects of poor positioning conditions during the preceding positioning, and

[0079] allows the height information to be promptly updated.

[0080] According to a further embodiment of the invention, there is provided a computer-readable recording medium having a program recorded thereon, the program causing a computer included in a positioning device including an estimated height storage section which stores an estimated height and a signal reception section which receives a satellite signal which is a signal from a satellite positioning system (SPS) satellite to execute:

[0081] calculating a height of a present position as a two-dimensional height by performing two-dimensional positioning which locates the present position based on the received satellite signals using the estimated height as a distance from the center of the earth;

[0082] calculating the height of the present position as a three-dimensional height by performing preliminary three-dimensional positioning which preliminarily locates the present position based on the received satellite signals without using the estimated height when performing the two-dimensional positioning;

[0083] selecting the two-dimensional height or the three-dimensional height for updating the estimated height stored in the estimated height storage section; and

[0084] updating the estimated height stored in the estimated height storage section using selected one of the two-dimensional height and the three-dimensional height.

[0085] Preferred embodiments of the invention are described below in detail with reference to the drawings.

[0086] The following embodiments illustrate specific preferred examples of the invention and are provided with various technologically preferred limitations. Note that the scope of the invention is not limited to the following embodiments unless there is a description limiting the invention.

[0087] FIG. **1** is a schematic view showing a positioning system **10** according to one embodiment of the invention.

[0088] As shown in FIG. **1**, the positioning system **10** includes a terminal **20**. The terminal **20** can receive signals S**1**, S**2**, S**3**, and S**4** from GPS satellites **12***a*, **12***b*, **12***c*, and **12***d* (SPS satellites), for example. The signals S**1** and the like exemplify satellite signals. The terminal **20** exemplifies a positioning device.

[0089] The terminal **20** is held by a user X and moves on a ground G.

[0090] The terminal **20** can perform three-dimensional positioning by receiving the signals S**1**, S**2**, S**3**, and S**4** from four GPS satellites **12***a*, **12***b*, **12***c*, and **12***d*, and generate information indicating the coordinates of the present position using the latitude, the longitude, and the height, for example.

[0091] The terminal **20** can perform two-dimensional positioning by receiving the signals S**1**, S**2**, and S**3** from three GPS satellites **12***a*, **12***b*, and **12***c*, for example. When performing two-dimensional positioning, the terminal **20** regards a center E of the earth as one satellite, and uses a height H as the pseudo-range between the center E and the terminal **20**. The terminal **20** can generate information indicating the coordinates of the present position using the latitude, the longitude, and the height by two-dimensional positioning. The term "two-dimensional positioning" used herein refers to one type of three-dimensional positioning, as described above. In two-dimensional positioning, the center E of the earth is used instead of one GPS satellite, and the height H is used as the pseudo-range.

[0092] When performing two-dimensional positioning, the terminal **20** must obtain information indicating the height H in advance. The terminal **20** can perform two-dimensional positioning with higher accuracy as the height H becomes more accurate.

[0093] The height H is the distance between the center E of the earth and the terminal **20**. The term "height" is hereinafter used to mean the distance between the center E of the earth and the terminal **20**.

[0094] The terminal **20** is a portable telephone, for example. The terminal **20** may be a personal handy-phone system (PHS), a personal digital assistance (PDA), a car navigation system, or the like. Note that the terminal **20** is not limited thereto.

[0095] The number of GPS satellites **12***a* and the like is not limited to four. For example, the number of GPS satellites **12***a* and the like may be three or five or more, differing from this embodiment.

[0096] The SPS satellite is not limited to the GPS satellite used in this embodiment. The SPS satellite also includes a satellite for the Galileo system, a quasi-zenith satellite, and the like.

[0097] (Main Hardware Configuration of Terminal **20**)

[0098] FIG. **2** is a schematic view showing the main hardware configuration of the terminal **20**.

[0099] As shown in FIG. **2**, the terminal **20** includes a computer which includes a bus **22**.

[0100] A central processing unit (CPU) **24**, a storage device **26**, and the like are connected with the bus **22**. The storage device **26** is a random access memory (RAM), a read only memory (ROM), or the like.

[0101] An input device **28** for inputting various types of information and the like and a GPS device **30** for receiving the signals S**1** and the like from the GPS satellites **12***a* and the like are also connected with the bus **22**. The GPS device **30** exemplifies a signal reception section.

[0102] A communication device **32** for communicating with the outside and a display device **34** for displaying various types of information are also connected with the bus **22**.

[0103] (Main Software Configuration of Terminal **20**)

[0104] FIG. **3** is a schematic view showing the main software configuration of the terminal **20**.

[0105] As shown in FIG. **3**, the terminal **20** includes a control section **100** which controls each section, a GPS section **102** corresponding to the GPS device **30** shown in FIG. **2**, a communication section **104** corresponding to the communication device **32**, a velocity measurement section **106**, and the like.

[0106] The velocity measurement section **106** generates velocity information **176** indicating the moving velocity of

the terminal **20** based on the Doppler shift of the signals S**1** and the like received by the GPS section **102** and the like (see paragraphs [0016] to of JP-A-8-68651, for example).

[0107] The control section **100** stores the velocity information **176** generated by the velocity measurement section **106** in a second storage section **150**.

[0108] The terminal **20** includes a first storage section **110** which stores various programs, and the second storage section **150** which stores various types of information.

[0109] Note that the terminal **20** may include a velocimeter (hardware), and the moving velocity of the terminal **20** may be measured using the velocimeter, differing from this embodiment.

[0110] As shown in FIG. **3**, the terminal **20** stores satellite orbital information **152** in the second storage section **150**. The satellite orbital information **152** includes an almanac **154** and an ephemeris **155**.

[0111] The almanac **154** is information indicating the approximate orbits of all of the GPS satellites **12***a* and the like (see FIG. **1**). The almanac **154** is effective for seven days, for example. Therefore, the terminal **20** decodes and updates the almanac **154** from one of the signals S**1** and the like from the GPS satellites **12***a* and the like every seven days.

[0112] The ephemeris **156** is information indicating the accurate orbit of each of the GPS satellites **12***a* and the like (see FIG. **1**) together with the acquisition time. The effective period of the ephemeris **156** is four hours (h), for example. Therefore, the terminal **20** decodes and updates the ephemeris **156** of each of the observable GPS satellites **12***a* and the like every four hours.

[0113] As shown in FIG. **3**, the terminal **20** stores one piece of estimated height information **158** indicating an estimated height H**1** in the second storage section **150**. The estimated height H**1** exemplifies an estimated height. The estimated height information **158** exemplifies estimated height information. The second storage section **150** exemplifies an estimated height storage section.

[0114] The estimated height H**1** is also called the height H**1**.

[0115] As shown in FIG. **3**, the terminal **20** stores a three-dimensional positioning program **112** in the first storage section **110**. The three-dimensional positioning program **112** is a program for causing the control section **100** to perform three-dimensional positioning based on the signals S**1** and the like received by the GPS section **102**. The three-dimensional positioning program **112** and the control section **100** exemplify a three-dimensional positioning section.

[0116] In more detail, the terminal **20** receives the signals S**1** and the like from four GPS satellites **12***a* and the like, and calculates the pseudo-range (i.e. distance between each of the GPS satellites **12***a* and the like and the terminal **20**) based on the delay time which is the difference between the time at which each of the signals S**1** and the like is transmitted from the GPS satellites **12***a* and the like and the time at which each of the signals S**1** and the like reaches the terminal **20**. The terminal **20** calculates (locates) the present position using the ephemeris **156** of each of the GPS satellites **12***a* and the like and the pseudo-range.

[0117] Three-dimensional coordinate information **160** includes three-dimensional latitude/longitude information **162** indicating the latitude and the longitude of the present position of the terminal **20**, and three-dimensional height information **164** indicating a height H**2***a* of the present position of the terminal **20**.

[0118] The control section **100** stores the generated three-dimensional coordinate information **160** in the second storage section **150**.

[0119] As shown in FIG. **3**, the terminal **20** stores a two-dimensional positioning program **114** in the first storage section **110**. The two-dimensional positioning program **114** is a program for causing the control section **100** to perform two-dimensional positioning. The two-dimensional positioning program **114** and the control section **100** exemplify a two-dimensional height calculation section. The control section **100** performs two-dimensional positioning when the control section **100** selects two-dimensional positioning based on a positioning method selection program **120** described later.

[0120] As shown in FIG. **3**, the two-dimensional positioning program **114** includes a preliminary three-dimensional positioning program **114***a*.

[0121] The preliminary three-dimensional positioning program **114***a* is a program for causing the control section **100** to perform three-dimensional positioning before two-dimensional positioning to calculate a height H**2***b* of the present position of the terminal **20**. Three-dimensional positioning performed based on the preliminary three-dimensional positioning program **114***a* is called preliminary three-dimensional positioning. The height H**2***b* exemplifies a three-dimensional height. The preliminary three-dimensional positioning program **114***a* and the control section **100** exemplify a three-dimensional height calculation section. The height H**2***b* is also called the three-dimensional height H**2***b*.

[0122] The control section **100** stores preliminary three-dimensional height information **166** indicating the height H**2***b* in the second storage section **150**.

[0123] The control section **100** performs two-dimensional positioning using the height H**1** based on a two-dimensional positioning program **114***b* after preliminary three-dimensional positioning.

[0124] The control section **100** calculates the latitude, the longitude, and a height H**2***c* of the present position of the terminal **20** by performing two-dimensional positioning. The height H**2***c* exemplifies a two-dimensional height. The height H**2***c* is also called the two-dimensional height H**2***c*.

[0125] In more detail, the terminal **20** receives the signals S**1** and the like from three GPS satellites **12***a* and the like, and calculates the pseudo-range (i.e. distance between each of the GPS satellites **12***a* and the like and the terminal **20**) based on the delay time which is the difference between the time at which each of the signals S**1** and the like is transmitted from the GPS satellites **12***a* and the like and the time at which each of the signals S**1** and the like reaches the terminal **20**. The terminal **20** regards the center E (see FIG. **1**) of the earth as one GPS satellite, and regards the estimated height H**1** as the pseudo-range between the terminal **20** and the center E of the earth.

[0126] The terminal **20** calculates the position of each of the GPS satellites **12***a* and the like in the orbit at the present time using the ephemeris **156** of each of the GPS satellites **12***a* and the like. The position of the center E of the earth is known. The terminal **20** calculates (locates) the present position based on the position of each of the GPS satellites **12***a* and the like in the orbit, the position of the center E of the earth, the pseudo-range, and the estimated height H**1**. As described above, the terminal **20** uses the center E of the earth and the estimated height H**1** for two-dimensional positioning. Therefore, the two-dimensional positioning results are affected by the estimated height H**1**.

[0127] The control section **100** generates two-dimensional coordinate information **168** by two-dimensional positioning, and stores the two-dimensional coordinate information **168** in the second storage section **150**. The two-dimensional coordinate information **168** includes two-dimensional latitude/longitude information **170** indicating the latitude and the longitude, and two-dimensional height information **172** indicating the height H**2***c*. The two-dimensional coordinate information **168** exemplifies positioning information.

[0128] The heights H**2***a*, H**2***b*, and H**2***c* are generically called a height H**2** or a positioning height H**2**.

[0129] It suffices that preliminary three-dimensional positioning be performed when performing two-dimensional positioning. Note that preliminary three-dimensional positioning may be performed after two-dimensional positioning, or may be performed in parallel with two-dimensional positioning, differing from this embodiment. Preliminary three-dimensional positioning may be continuously performed during a period from the commencement of two-dimensional positioning to calculation of the two-dimensional height H**2***c*.

[0130] Specifically, since the reception state of the signals S**1** and the like changes from moment to moment, the control section **100** may be able to perform three-dimensional positioning even if the control section **100** has selected two-dimensional positioning based on the positioning method selection program **120** described later. Specifically, the control section **100** performs preliminary three-dimensional positioning to calculate the three-dimensional height H**2***b*, if possible, even if the control section **100** has selected two-dimensional positioning.

[0131] As shown in FIG. **3**, the terminal **20** stores a positioning condition information generation program **116** in the first storage section **110**. The positioning condition information generation program **116** is a program for causing the control section **100** to generate positioning condition information **174** indicating the positioning conditions when the control section **100** generates the three-dimensional coordinate information **160** and the two-dimensional coordinate information **168**.

[0132] The positioning condition information **174** is information indicating the PDOP, the number of positioning satellites, and the positioning error, for example.

[0133] Note that the positioning condition information may be information indicating one or two of the PDOP, the number of positioning satellites, and the positioning error, differing from this embodiment.

[0134] In three-dimensional positioning, preliminary three-dimensional positioning, and two-dimensional positioning, each of the signals S**1** and the like is received using a reception method (operation mode) corresponding to the field intensity (signal strength).

[0135] FIG. **4** is a view showing an example of the operation mode of the terminal **20**.

[0136] As shown in FIG. **4**, the terminal **20** can operate in a search mode M**1**, a first tracking mode M**2**, and a second tracking mode M**3**.

[0137] The search mode M**1** is a mode for acquiring the signals S**1** and the like. Therefore, the terminal **20** searches for a wide frequency range of 3 kHz in the search mode M**1**, for example.

[0138] The first tracking mode M**2** (hereinafter called "mode M**2**") is a positioning mode in which the terminal **20** tracks the signals S**1** and the like after acquiring the signals S**1** and the like. The mode M**2** is an operation mode (positioning mode) when the signal strength (field intensity) is high. The term "high signal strength" refers to a signal strength of −139 dBm or more, for example.

[0139] An accumulation time (incoherent time) t**1** in the mode M**2** is one second, for example.

[0140] The second tracking mode M**3** (hereinafter called "mode M**3**") is a positioning mode in which the terminal **20** tracks the signals S**1** and the like after acquiring the signals S**1** and the like. The mode M**3** is an operation mode (positioning mode) when the signal strength is low. The term "low signal strength" refers to a signal strength of −160 dBm or more and less than −139 dBm, for example.

[0141] An accumulation time (incoherent time) t**2** in the mode M**3** is two seconds, for example.

[0142] The accumulation time t**2** in the mode M**3** is longer than the accumulation time t**1** in the mode M**2**.

[0143] The terminal **20** has a plurality of positioning modes with different operating signal strengths, as described above.

[0144] As shown in FIG. **3**, the terminal **20** stores an environment determination program **118** in the first storage section **110**. The environment determination program **118** is a program for causing the control section **100** to determine the positioning environment when performing three-dimensional positioning based on the first positioning program **112** and the positioning environment when performing two-dimensional positioning based on the two-dimensional positioning program **114**. The environment determination program **118** and the control section **100** exemplify a positioning environment determination section.

[0145] FIGS. **5** and **6** are views illustrative of the process based on the environment determination program **118**.

[0146] As shown in FIG. **5**, the control section **100** classifies the field intensity (signal strength) of the signals S**1** and the like into a strong electric field and a weak electric field based on the environment determination program **118**. The strong electric field has a field intensity in which the terminal **20** operates in the mode M**2**. The weak electric field has a field intensity in which the terminal **20** operates in the mode M**3**.

[0147] The control section **100** classifies the strong electric field into a first strong electric field, a second strong electric field, and a third strong electric field.

[0148] The first strong electric field has a field intensity of a1 or more and less than a2. The second strong electric field has a field intensity of a2 or more and less than a3. The third strong electric field has a field intensity of a3 or more. a1, a2, and a3 are field intensity threshold values. a2 is greater than a1, and a3 is greater than a2. a1 is −140, for example. a2 is −130, for example. a3 is −124, for example.

[0149] The control section **100** classifies the weak electric field into a first weak electric field and a second weak electric field.

[0150] The first weak electric field has a field intensity of b1 or more and less than b2. The second weak electric field has a field intensity of b2 or more and less than b3. b1, b2, and b3 are field intensity threshold values. b2 is greater than b1, and b3 is greater than b2. b1 is −160 dBm, for example. b2 is −150 dBm, for example. b3 is −140 dBm, for example.

[0151] As shown in FIG. **6**, the control section **100** classifies the positioning environment into a first environment to a ninth environment corresponding to the operation mode and the field intensity based on the environment determination program **114**. The positioning specification is specified for each positioning environment.

[0152] As shown in FIG. **3**, the terminal **20** stores the positioning method selection program **120** in the first storage section **110**. The positioning method selection program **120** is a program for causing the control section **100** to select three-dimensional positioning or two-dimensional positioning based on the positioning environment. The positioning method selection program **120** and the control section **100** exemplify a positioning method selection section.

[0153] In more detail, the control section **100** selects two-dimensional positioning when the positioning environment is the third environment, the fourth environment, the fifth environment, the sixth environment, or the seventh environment, and a gain described later is 5 or more.

[0154] The third environment, the fourth environment, the fifth environment, the sixth environment, and the seventh environment are environments in which multipaths easily occur. The reliability of the height calculated by positioning is low in an environment in which multipaths occur. If the gain is 5 or more, the estimated height H**1** has been updated a number of times equal to or greater than a specific number. Therefore, the estimated height H**1** is considered to be stable at a value close to the true height.

[0155] The control section **100** selects three-dimensional positioning when the positioning environment is the first environment, the second environment, the eighth environment, or the ninth environment, or when the gain described later is less than 5.

[0156] Since the reception environment is excellent in the first environment and the second environment, the reliability of the height calculated by positioning is high. Therefore, three-dimensional positioning is suitable in comparison with two-dimensional positioning.

[0157] Since the reception environment is very poor in the eighth environment and the ninth environment, the reliability (accuracy) of the height calculated by positioning is extremely low. Therefore, if the estimated height H**1** is continuously updated with the height calculated by positioning, the accuracy of the estimated height H**1** deteriorates extremely. In this case, the height calculated by positioning has an accuracy higher than that of the estimated height H**1** which has been updated a number of times with the inaccurate positioning height and of which the accuracy has extremely deteriorated, since the deterioration in accuracy is not accumulated. Accordingly, the control section **100** selects three-dimensional positioning in the eighth environment and the ninth environment. Specifically, although two-dimensional positioning and three-dimensional positioning exhibit poor accuracy in the eighth environment and the ninth environment, three-dimensional positioning is likely to exhibit an accuracy higher than that of two-dimensional positioning.

[0158] If the gain is less than 5, the number of updates of the estimated height H**1** is insufficient. Therefore, the estimated height H**1** is considered to differ from the true height to a large extent. Accordingly, the control section **100** selects three-dimensional positioning.

[0159] The conditions for selecting two-dimensional positioning are called "two-dimensional positioning execution conditions".

[0160] The control section **100** selects three-dimensional positioning or two-dimensional positioning based on the positioning environment, as described above. The control section **100** generates the three-dimensional coordinate information **160** or the two-dimensional coordinate information **168** corresponding to the selected three-dimensional positioning or two-dimensional positioning, and displays the three-dimensional coordinate information **160** or the two-dimensional coordinate information **168** on the display device **34**.

[0161] The positioning height H**2** for updating the estimated height H**1** is selected and the estimated height H**1** is updated while generating the coordinate information to be displayed on the display device **34**, as described below.

[0162] As shown in FIG. **3**, the terminal **20** stores a height selection program **124** in the first storage section **10**. The height selection program **124** is a program for causing the control section **100** to select the positioning height H**2** for updating the estimated height H**1**. The height selection program **124** and the control section **100** exemplify a height selection section.

[0163] The control section **100** selects the height H**2***a* when three-dimensional positioning has been performed.

[0164] The control section **100** selects the height H**2***b* or H**2***c* when two-dimensional positioning has bee performed.

[0165] A configuration for the terminal **20** to select the height H**2***b* or H**2***c* when two-dimensional positioning is described below.

[0166] The control section **100** selects the height H**2***b* or H**2***c* based on the movement state of the terminal **20** and the reliability of the two-dimensional coordinate information **168**.

[0167] In more detail, the control section **100** selects the height H**2***c* when the terminal **20** does not move (stationary state). The control section **100** determines that the terminal **20** remains stationary when the velocity V indicated by the velocity information **176** is zero.

[0168] Since the true height does not change when the terminal **20** remains stationary, the effects of a poor reception environment can be reduced by using the height H**2***c*.

[0169] On the other hand, the true height may change when the terminal **20** moves. Therefore, the control section **100** selects the height H**2***b* or H**2***c* based on the reliability of the two-dimensional coordinate information **168**.

[0170] For example, the control section **100** determines that the two-dimensional coordinate information **168** has sufficient reliability when four or more satellites are used for positioning and the degree of convergence is less than a predetermined threshold value d**1**, and selects the height H**2***c*. On the other hand, the control section **100** determines that the two-dimensional coordinate information **168** has insufficient reliability when four or more satellites are not used for positioning or the degree of convergence is equal to or greater than the predetermined threshold value d**1**, and selects the height H**2***b*.

[0171] The degree of convergence is the degree of convergence of a position calculation, and is calculated in units of multiple position calculations performed during one positioning. A value indicating the degree of convergence decreases as the degree of convergence becomes higher. The degree of convergence used as the determination criterion is the degree of convergence of one position calculation selected from a plurality of position calculations.

[0172] The reliability of the two-dimensional coordinate information **168** increases as the number of satellites used for positioning becomes larger. Specifically, positioning calculations can be performed using a larger number of satellite sets as the number of satellites used for positioning becomes

larger. The reliability of the two-dimensional coordinate information **168** increases as the degree of convergence becomes higher.

[0173] A configuration for the terminal **20** to update the estimated height H**1** is described below.

[0174] As shown in FIG. **3**, the terminal **20** stores an estimated height updating program **126** in the first storage section **110**. The estimated height updating program **126** is a program for causing the control section **100** to update the height H**1** based on the height H**2***a*, H**2***b*, or H**2***c*. The estimated height updating program **126** and the control section **100** exemplify an updating section.

[0175] The estimated height updating program **126** includes a basic updating program **126***a*, an adaptive control program **126***b*, and an initial updating program **126***c*.

[0176] The control section **100** determines whether or not basic update conditions are satisfied based on the estimated height updating program **126**. The basic update conditions are conditions for the terminal **20** to update the estimated height H**1** by changing a gain counter by one corresponding to the moving velocity and performing adaptive control under specific conditions. This update process is called a basic update process. The basic update process may be performed when the estimated height H**1** has specific reliability. Therefore, the basic update conditions are conditions for the estimated height H**1** to have specific reliability. The basic update conditions are specified in advance. The basic update conditions are conditions whereby the estimated height has been updated five times or more and the gain is 5 or more, for example. It is considered that the estimated height H**1** is close to the true height if the above conditions are satisfied.

[0177] The basic update conditions are not limited to the above conditions. For example, the basic update conditions may be conditions whereby the estimated height has been updated three times or more and the gain is 5 or more.

[0178] The estimated height updating program **126** and the control section **100** also exemplify an estimated height evaluation section.

[0179] When the estimated height H**1** satisfies the basic update conditions, the control section **100** updates the estimated height H**1** based on the basic updating program **126***a* and the adaptive control program **126***b*, as described below.

[0180] The initial updating program **126***c* is an updating program executed when the basic update conditions are not satisfied.

[0181] The basic updating program **126***a* is described below.

[0182] The basic updating program **126***a* is a program for causing the control section **100** to perform the basic update process described below.

[0183] The control section **100** determines the weight alpha (hereinafter called "gain alpha") of the estimated height H**1** with respect to the height H**2***a* and the like when updating the height H**1** based on the height H**2***a*, H**2***b*, or H**2***c*.

[0184] FIG. **7** is a view showing an example of the process based on the basic updating program **126***a*.

[0185] The basic update process described below is performed when the estimated height H**1** satisfies the basic update conditions.

[0186] As shown in FIG. **7**A, the terminal **20** stores a gain table including a gain counter and a gain as the basic updating program **126***a*. The gain is information indicating the weight of the estimated height H**1**. The gain counter is information for designating the gain. The gain determination program **126** sets the gain counter to 5 (gain alpha=3.5) as an initial setting, for example.

[0187] When the estimated height H**1** satisfies the basic update conditions, the control section **100** increases the gain counter by one to increase the gain alpha when the velocity V indicated by the velocity information **176** is equal to or less than 60 kilometers per hour (km/h) (hereinafter called "principle operation"). For example, the control section **100** sets the gain counter to 6 (gain alpha=4) in the first update operation. The control section **100** sets the gain counter to 7 (gain alpha=4.5) in the second update operation. As described above, the control section **100** increases the gain alpha as the number of updates of the estimated height H**1** increases. Note that the term "increasing the gain alpha" is also referred to as "enhancing the gain alpha". Note that the term "reducing the gain alpha" is also referred to as "weakening the gain alpha". The control section **100** gradually increases the gain by increasing the gain counter by one each time the estimated height H**1** is updated. This allows the estimated height H**1** to gradually approach the true height.

[0188] When the velocity V indicated by the velocity information **176** is not equal to or less than 60 kilometers per hour (km/h), the control section **100** decreases the gain counter by one when updating the estimated height H**1**. This allows the estimated height H**1** to be updated by incorporating the element of the new positioning height H**2** or the like while minimizing the effects of the positioning height H**2** when updating the height H**1**.

[0189] As shown in FIG. **7**B, the updated estimated height H**1** becomes closer to the held estimated height H**1** as the gain alpha becomes greater. The updated estimated height H**1** becomes closer to the height H**2** as the gain alpha becomes smaller. Therefore, the terminal **20** increases the gain counter when it is appropriate to increase the weight of the estimated height H**1**, and decreases the gain counter when it is appropriate to increase the weight of the positioning height H**2**.

[0190] As the gain determination method, one gain may be allocated to two values of the gain counter, as shown in FIG. **7**C, differing from this embodiment.

[0191] The control section **100** updates the estimated height H**1** with the height H**2***a*, H**2***b*, or H**2***c* using the set gain alpha.

[0192] In more detail, the control section **100** updates the estimated height H**1** using the set gain alpha, and calculates the updated height H**1***a*. The updated height H**1***a* is used as the new estimated height H**1**.

[0193] The control section **100** stores updated height information **178** indicating the updated height H**1***a* in the second storage section **150**. In the specification, the term "calculation of the updated height H**1***a*" is synonymously used with the term "update of the estimated height H**1**".

[0194] The updated height H**1***a* indicated by the updated height information **178** is calculated by H**1***a*=H**1**+(H**2**−H**1**)/alpha, for example.

[0195] When the control section **100** has generated the updated height information **178**, the control section **100** increases the number of updates n indicated by the number-of-updates information **180** by one.

[0196] The adaptive control program **126***b* is described below.

[0197] The adaptive control program **126***b* is a program for causing the control section **100** to change only the update method from the basic update process based on the difference

in height dH and the degree of positioning reliability while maintaining the gain counter. Control based on the adaptive control program **126***b* is performed during the above basic update process.

[0198] The degree of positioning reliability is a value indicating the degree of positioning reliability during positioning for calculating the height H**2***b* or H**2***c*, and is specified by the positioning error, the positional dilution of precision (PDOP), the number of satellites used for positioning, and the like. The degree of positioning reliability is indicated by seven-grade indices (0, 1, 2, 3, 4, 5, 6, and 7), for example. The smaller the value, the higher the degree of reliability. The threshold value d**2** is "2" (second grade). The index becomes smaller as the positioning error becomes smaller. The index becomes smaller as the PDOP becomes smaller. The index becomes smaller as the number of satellites used for positioning becomes larger.

[0199] The control section **100** determines whether or not gain temporary change conditions are satisfied based on the adaptive control program **126***b*. The gain temporary change conditions are conditions for changing the gain so that the gain is applied to only the present update operation of the estimated height H**1**. The gain temporary change conditions are satisfied when the currently calculated height H**2** has high reliability (e.g. the number of satellites used for positioning is five or more and the PDOP is three or less).

[0200] When the control section **100** has determined that the positioning conditions satisfy the gain temporary change conditions, the control section **100** decreases the gain by one while maintaining the gain counter. Therefore, when the present height H**2** has high reliability, the gain can be temporarily changed corresponding to the reliability of the height H**2**. This allows the estimated height H**1** to be updated while reflecting the reliability of the height H**2** which changes from moment to moment.

[0201] When the control section **100** has determined that the positioning conditions do not satisfy the gain temporary change conditions, the control section **100** maintains the gain.

[0202] The control section **100** then calculates the difference in height dH between the estimated height H**1** and the height H**2***b* or H**2***c* selected based on the height selection program **124** based on the adaptive control program **126***b*. When the degree of positioning reliability is high, the estimated height H**1** should be updated while increasing the effects of the positioning height H**2**. However, even if the degree of positioning reliability calculated during positioning is high, the degree of positioning reliability is not reliable when the difference in height dH is large. Therefore, the effects of the positioning height H**2** on the update of the estimated height H**1** should be reduced.

[0203] Therefore, when the difference in height dH is equal to or greater than 1000 meters (m) and the index is equal to or greater than the specific threshold value d**2**, the control section **100** adds 1/64th of the difference in height dH to the estimated height H**1** and updates the estimated height H**1**. This allows the estimated height H**1** to be updated while decreasing the effects of the positioning height H**2** when the difference in height dH is large while taking the effects of the positioning height H**2** into consideration to some extent. This prevents a situation in which the estimated height H**1** rapidly changes away from the true value.

[0204] When the difference in height dH is equal to or greater than 1000 meters (m) and the index is less than the specific threshold value d**2**, the control section **100** adds 1/4th of the difference in height dH to the estimated height H**1** and updates the estimated height H**1**. This allows the effects of the positioning height H**2** to be increased when the degree of positioning reliability of the positioning height H**2** is high.

[0205] When the basic update conditions are satisfied and the reliability of the estimated height H**1** is high, if the degree of positioning reliability is equal to or greater than the threshold value d**2** and the difference in height between the estimated height H**1** and the height H**2** is as large as 1000 meters, the estimated height H**1** can be made close to the true height by updating the estimated height H**1** while reducing the effects of the height H**2** and taking the effects of the height H**2** calculated by positioning into consideration.

[0206] When updating the estimated height H**1** depending the reliability of the height H**2**, the reliability of the height H**2** is determined based on whether or not the index indicating the degree of positioning reliability is larger than the threshold value d**2**. The reliability of the height H**2** is increased when the index is smaller than the threshold value d**2**, and the reliability of the height H**2** is decreased when the index is larger than the threshold value d**2**.

[0207] When the terminal **20** has determined that the index is equal to or larger than the threshold value d**2**, the terminal **20** adds 1/64th of the difference in height to the estimated height H**1**, as described above.

[0208] When the terminal **20** has determined that the index is less than the threshold value d**2**, the terminal **20** adds 1/4th of the difference in height to the estimated height H**1**.

[0209] When the difference in height dH is equal to or greater than 500 meters (m) and the degree of positioning reliability is equal to or greater than the threshold value d**2**, the control section **100** adds 1/32nd of the difference in height dH to the estimated height H**1** and updates the estimated height H**1**.

[0210] When the difference in height dH is equal to or greater than 500 meters (m) and the degree of positioning reliability is less than the threshold value d**2**, the control section **100** adds half of the difference in height dH to the estimated height H**1** and updates the estimated height H**1**.

[0211] When the difference in height dH is equal to or greater than 500 meters (m), the reliability of the height H**2** is high in comparison with the case where the difference in height is equal to or greater than 1000 meters (m). In this case, the index indicating the degree of positioning reliability is small. Therefore, the control section **100** adds 1/32nd of the difference in height dH to the estimated height H**1** instead of 1/64th of the difference in height dH in order to increase the effects of the height H**2** in comparison with the case where the difference in height is equal to or greater than 1000 meters (m).

[0212] When the difference in height dH is equal to or greater than 100 meters (m) and the degree of positioning reliability is equal to or greater than the threshold value d**2**, the control section **100** adds 1/16th of the difference in height dH to the estimated height H**1** and updates the estimated height H**1**.

[0213] When the difference in height dH is equal to or greater than 100 meters (m) and the degree of positioning reliability is less than the threshold value d**2**, the control section **100** adds half of the difference in height dH to the estimated height H**1** and updates the estimated height H**1**.

[0214] The initial updating program **126***c* is described below.

[0215] The control section **100** calculates the difference in height dH between the estimated height H**1** and the height H**2***b* or H**2***c* selected based on the height selection program **124** based on the initial updating program **126***c*. The initial updating program **126***c* and the control section **100** exemplify a difference-in-height calculation section.

[0216] When the difference in height dH is less than h (threshold value) meters (m), the control section **100** updates the height H**1** by averaging the estimated height H**1** and the height H**2**. The threshold value h is 50 meters (m), for example. When the difference in height is less than 50 meters (m), it is considered that the estimated height H**1** has a specific degree of reliability. Therefore, the control section **100** updates the estimated height H**1** while taking the held estimated height H**1** into consideration.

[0217] The control section **100** increases the gain counter corresponding to the degree of positioning reliability. The degree of positioning reliability is determined based on the number of satellites used for positioning and the positioning error. For example, when the number of satellites used for positioning is five or more and the positioning error is 30 meters (m) or less, the control section **100** increases the gain counter by two. Specifically, the gain is increased to a large extent in comparison with the basic update process in which the gain is increased by one. Therefore, the gain can be promptly increased to a specific value (e.g. 5). This allows the basic update conditions to be promptly satisfied.

[0218] When the control section **100** has determined that the difference in height dH is equal to or greater than h (threshold value) meters (m), the control section **100** updates the height H**1** using the height H**2** as the estimated height H**1**. It is considered that the estimated height H**1** is not reliable when the basic update conditions are not satisfied and the difference in height dH is equal to or greater than the threshold value h. Therefore, the control section **100** updates the estimated height H**1** without taking the held estimated height H**1** into consideration.

[0219] The control section **100** then initializes the gain counter. Specifically, the control section **100** sets the gain counter to "5" (i.e. initial setting). The control section **100** may set the gain counter in the value that is less than "5". For example, when the number of satellites used for positioning is five or more and the positioning error is 30 meters (m) or less, the control section **100** sets the gain counter to "2". Otherwise, the control section **100** sets the gain counter to "1". Therefore, the gain counter can be promptly increased to a specific value.

[0220] The estimated height H**1** is updated as described above.

[0221] FIG. **8** is a view showing an example of a state in which the height information **158** is updated.

[0222] As shown in FIG. **8**, the height H**1** indicated by the height information **158** approaches the true height H and becomes stable near the true height H as the number of updates with the height H**2** increases.

[0223] The positioning system **10** is configured as described above.

[0224] As described above, the terminal **20** can calculate the two-dimensional height H**2***c*. Therefore, the terminal **20** can calculate the height even if the two-dimensional positioning execution conditions are satisfied (e.g. when three-dimensional positioning is not appropriate).

[0225] The terminal **20** can calculate the three-dimensional height H**2***b* by preliminary three-dimensional positioning when performing two-dimensional positioning. There may be a case where three-dimensional positioning can be performed, even if three-dimensional positioning is not appropriate. The three-dimensional height H**2***b* may be appropriate for updating the estimated height H**1** even if two-dimensional positioning is appropriate for calculating the located position and outputting the information to the display device **34**.

[0226] One of the features of this embodiment is to perform preliminary three-dimensional positioning when performing two-dimensional positioning. The number of satellite sets which can be used for positioning is increased in two-dimensional positioning in comparison with three-dimensional positioning as long as the two-dimensional positioning execution conditions are satisfied, whereby the positioning accuracy is improved. Specifically, while four satellites are necessary for one positioning calculation of three-dimensional positioning, only three satellites are necessary for one positioning calculation of two-dimensional positioning. In three-dimensional positioning, it may be necessary to use a satellite signal with a poor reception state (e.g. signal strength is weak) in order to provide satellites in a number necessary for the positioning calculation. On the other hand, since the number of satellites necessary for the positioning calculation of two-dimensional positioning is reduced to three, a satellite signal with a poor reception state may be excluded, whereby the positioning accuracy is improved.

[0227] The three-dimensional height H**2***b* calculated by preliminary three-dimensional positioning may be used to update the estimated height H**1** for the following reason. Specifically, since the estimated height H**1** used for two-dimensional positioning is calculated by positioning and changes to only a small extent, the followability of the height may deteriorate. Therefore, the followability with respect to a change in the true height is improved using the three-dimensional height H**2***b* calculated by preliminary three-dimensional positioning.

[0228] Therefore, the terminal **20** calculates the two-dimensional height H**2***c* and the three-dimensional height H**2***b*. This increases the degrees of freedom of selection of the height for updating the estimated height H**1**.

[0229] The terminal **20** can selectively use the height H**2***a*, H**2***b*, or H**2***c* for updating the estimated height H**1**.

[0230] In two-dimensional positioning, the center of the earth is regarded as one satellite and used for positioning. Specifically, two-dimensional positioning is performed on the assumption that the estimated height H**1** is the pseudo-range between the center of the earth and the terminal **20**. Therefore, two-dimensional positioning exhibits higher positioning accuracy when the accuracy of the estimated height H**1** is high.

[0231] However, since it is considered that the true height changes in a reception state such as when the terminal **20** moves at a velocity equal to or higher than a specific velocity, three-dimensional positioning which does not use the estimated height H**1** provides excellent followability with respect to the true movement state, whereby the positioning accuracy is increased.

[0232] Therefore, even if the estimated height H**1** is nearly accurate, the accuracy of the height H**2***c* calculated by preliminary three-dimensional positioning may be higher than that of the height H**2***c* calculated by two-dimensional positioning depending on the reception state.

[0233] The terminal **20** can select the height H2*b* or H2*c* depending on the reception environment during two-dimensional positioning, for example.

[0234] When the terminal **20** has performed three-dimensional positioning, the terminal **20** can select the height H2*a*.

[0235] The terminal **20** can update the height H1 using the height H2*a*, H2*b*, or H2*c*. Specifically, even if three-dimensional positioning is not appropriate, the terminal **20** can update the height H1 using the height H2*a*, H2*b*, or H2*c* having relatively high reliability. Therefore, the terminal **20** can promptly update the height H1.

[0236] Since the height H2 is new information generated by positioning, the height H1 which has been held is corrected by new information by updating the height H1 using the height H2. This enables the height H1 to be made closer to the true height.

[0237] Moreover, since the terminal **20** can calculate the two-dimensional height H2*c* and the three-dimensional height H2*b* and select a more suitable height, the estimated height H1 can be further made closer to the true height.

[0238] Since the terminal **20** can hold and update only one estimated height H1, the load imposed on the storage for holding the height data is reduced.

[0239] Therefore, the terminal **20** allows a reduction in load imposed on the storage for holding the height data, ensures acquisition of accurate height information used for two-dimensional positioning while reducing the effects of poor positioning conditions during the preceding positioning, and allows the height information to be promptly updated.

[0240] The terminal **20** updates the estimated height H1 in the basic update process while increasing the gain alpha as the number of updates of the estimated height H1 increases.

[0241] After the accurate height information has been obtained as a result of updating the height H1 a number of times, although it is necessary to update the height H1 using the new height H2, the accuracy of the height H1 can be increased by reducing the weight of the new height H2 and increasing the weight of the height H1.

[0242] Since the terminal **20** updates the height H1 while increasing the weight of the height H1 which has been held as the number of updates of the height H1 increases, the height H1 can be made more accurate.

[0243] The terminal **20** updates the height H1 while increasing the gain alpha when the moving velocity V is within a predetermined velocity allowable range, and updates the height H1 while reducing the gain alpha when the moving velocity V is not within the velocity allowable range.

[0244] In general, when an object moves on the surface of the earth, the amount of vertical movement is small when the object moves at a low speed in comparison with the case where the object moves at a high speed. In other words, when an object moves on the surface of the earth, the amount of vertical movement is large when the object moves at a high speed in comparison with the case where the object moves at a low speed.

[0245] Therefore, the accuracy of the height H1 can be increased by reducing the weight of the new height H2 and increasing the weight of the height H1 when the terminal **20** moves at a low speed in comparison with the case where the terminal **20** moves at a high speed.

[0246] The terminal **20** updates the height H1 while increasing the gain alpha when the terminal **20** moves at a low speed in comparison with the case where the terminal **20** moves at a high speed. The terminal **20** updates the height H1 while reducing the gain alpha when the terminal **20** moves at a high speed in comparison with the case where the terminal **20** moves at a low speed. Therefore, the terminal **20** can update the height H1 with a gain alpha corresponding to the velocity to increase the accuracy of the height H1.

[0247] The terminal **20** can update the height H1 using the gain alpha set based on the positioning conditions and the moving velocity. Since the height H2 is new information generated by positioning, the height H1 is corrected by new information by updating the height H1 using the height H2. This enables the height indicated by the height H1 to be made closer to the true height.

[0248] The terminal **20** can determine whether or not the basic update conditions are satisfied depending on the number of updates of the height H1.

[0249] When the number of updates of the height H1 is 5 or more and the gain is 5 or more, the terminal **20** can generate the two-dimensional coordinate information **168** by performing two-dimensional positioning based on the signals S1 and the like from the GPS satellite **12***a* and the height H1. The accuracy of the height H1 can increased by updating the height H1 using the new height H2. The error of each height H2 is reduced by updating the height H1 a number of times. Therefore, the height H1 after being updated five times or more is close to the true height. Accordingly, the positioning accuracy of two-dimensional positioning using the resulting height H1 is increased. When the gain has reached 5 or more, the reliability of the estimated height H1 has been increased.

[0250] Two-dimensional positioning using the accurate height H1 exhibits higher positioning accuracy than that of three-dimensional positioning. Specifically, since the number of sets of observable GPS satellites **12***a* and the like used for positioning is larger for two-dimensional positioning than for three-dimensional positioning, positioning results more accurately indicating the present position can be selected from a number of positioning results. For example, when the number of observable GPS satellites **12***a* and the like is five, since three-dimensional positioning uses four or more GPS satellites for one positioning calculation, the number of sets of GPS satellites which may be used for positioning is six in total (i.e. five sets of four GPS satellites and one set of five GPS satellites). On the other hand, when the number of observable GPS satellites **12***a* and the like is five, since two-dimensional positioning uses three or more GPS satellites for one positioning calculation, the number of sets of GPS satellites which may be used for positioning is sixteen in total (i.e. ten sets of three GPS satellites, five sets of four GPS satellites, and one set of five GPS satellites).

[0251] When the number of updates of the height H1 is within a two-dimensional positioning allowable count, the two-dimensional coordinate information **168** generated by two-dimensional positioning using the updated height H1 is accurate position information close to the true position.

[0252] The configuration of the positioning system **10** according to this embodiment has been described above. An operation example of the positioning system **10** is described below mainly using FIGS. **9** to **12**.

[0253] FIGS. **9** to **12** are schematic flowcharts showing an operation example of the positioning system **10** according to this embodiment.

[0254] The operation in which the terminal **20** updates the height H1 with the height H2 is also called filtering. The gain alpha is also called the filtering gain alpha.

[0255] In FIGS. **9** to **12**, the terminal **20** has received the signals S**1** and the like from the GPS satellites **12***a* and the like and continuously locates the position. FIGS. **9** to **12** shows the method of updating the height H**1** during positioning.

[0256] The terminal **20** determines whether or not the two-dimensional positioning execution conditions are satisfied (step ST**1** in FIG. **9**).

[0257] When the terminal **20** has determined that the two-dimensional positioning execution conditions are not satisfied, the terminal **20** performs three-dimensional positioning (step ST**2**A), and holds the three-dimensional height H**2***a* (step ST**3**A). The terminal **20** uses the three-dimensional height H**2***a* for updating the estimated height H**1** (step ST**8**A).

[0258] When the terminal **20** has determined that the two-dimensional positioning execution conditions are satisfied in the step ST**1**, the terminal **20** performs preliminary three-dimensional positioning and determines whether or not preliminary three-dimensional positioning has succeeded (step ST**2**). The terminal **20** determines that preliminary three-dimensional positioning has succeeded when the positioning calculation has been completed and the located position has been calculated. The step ST**2** exemplifies a three-dimensional height calculation step.

[0259] When the terminal **20** has determined that preliminary three-dimensional positioning has succeeded, the terminal **20** holds the three-dimensional height H**2***b* (step ST**3**).

[0260] The terminal **20** then performs two-dimensional positioning, and determines whether or not two-dimensional positioning has succeeded (step ST**4**). The terminal **20** determines that two-dimensional positioning has succeeded when the positioning calculation has been completed and the located position has been calculated. The step ST**4** exemplifies a two-dimensional height calculation step.

[0261] When the terminal **20** has determined that preliminary three-dimensional positioning has not succeeded in the step ST**2**, the three-dimensional height H**2***b* cannot be calculated. Therefore, the terminal **20** proceeds to the step ST**4**.

[0262] When the terminal **20** has determined that two-dimensional positioning has succeeded, the terminal **20** holds the two-dimensional height H**2***c* (step ST**5**).

[0263] When the terminal **20** has determined that two-dimensional positioning has not succeeded, the terminal **20** does not update the estimated height H**1** (step ST**8**B). Since positioning has failed when two-dimensional positioning has not succeeded, the estimated height H**1** cannot be updated.

[0264] The terminal **20** determines whether or not the terminal **20** holds the three-dimensional height H**2***b* after the step ST**5** (step ST**6**). When the terminal **20** has determined that the terminal **20** does not hold the three-dimensional height H**2***b*, the terminal **20** uses the two-dimensional height H**2***c* for updating the estimated height H**1** (step ST**8**).

[0265] When the terminal **20** has determined that the terminal **20** holds the three-dimensional height H**2***b* in the step ST**6**, the terminal **20** determines the positioning state during two-dimensional positioning (step ST**7**). The terminal **20** selects the two-dimensional height H**2***c* or the three-dimensional height H**2***b* in this step ST**7** in order to update the estimated height H**1**. The step ST**7** exemplifies a height selection step.

[0266] The details of the step ST**7** are described below with reference to FIG. **10**.

[0267] The terminal **20** determines whether or not the terminal **20** moves (step ST**101** in FIG. **10**).

[0268] When the terminal **20** has determined that the terminal **20** does not move, the terminal **20** selects the two-dimensional height H**2***c* (step ST**104**).

[0269] When the terminal **20** has determined that the terminal **20** moves, the terminal **20** determines whether or not four or more satellites are used (step ST**102**).

[0270] When the terminal **20** has determined that four or more satellites are not used, the terminal **20** selects the three-dimensional height H**2***b* (step ST**104**A).

[0271] When the terminal **20** has determined that four or more satellites are used, the terminal **20** determines whether or not the degree of convergence of the position calculation is less than the threshold value d**1** (step ST**103**).

[0272] When the terminal **20** has determined that the degree of convergence is not less than the threshold value d**1**, the terminal **20** selects the three-dimensional height H**2***b* (step ST**104**A).

[0273] When the terminal **20** has determined that the degree of convergence is less than the threshold value d**1**, the terminal **20** selects the two-dimensional height H**2***c* (step ST**104**).

[0274] The terminal **20** can select the height H**2** used to update the estimated height H**1** by the above steps ST**1** to ST**8** (**8**A, **8**B). Or, the terminal **20** can determine that the terminal **20** does not update the estimated height H**1**.

[0275] The method of updating the estimated height H**1** is described below with reference to FIGS. **11** and **12**.

[0276] The terminal **20** determines whether or not the electric field is weak and the number of satellites which are being sought is one or more (step ST**21** in FIG. **11**). The step ST**21** is a step following the step ST**8** or ST**8**A (see FIG. **9**). The term "satellite which is being sought" refers to a satellite of which the signal S**1** or the like has not be acquired the terminal **20** and which has not been tracked by the terminal **20**. The term "weak electric field" refers to the eighth environment and the ninth environment. Even if the measurement (code phase and signal strength) of the satellite which is being sought is calculated, the reliability of the measurement is low.

[0277] When the terminal **20** has determined that the electric field is weak and the number of satellites which are being sought is one or more in the step ST**21**, the terminal **20** does not update the estimated height H**1** (step ST**31**). Since the reliability of the calculated height H**2** is low under such conditions, the reliability of the estimated height H**1** can be maintained by maintaining the held estimated height H**1**. Since the degree of positioning reliability of the height H**2** is considerably low in a weak electric field, the accuracy of the estimated height H**1** deteriorate is the estimated height H**1** is updated using the height H**2**,

[0278] When the terminal **20** has determined that the electric field is not weak and the number of satellites which are being sought is not one or more, the terminal **20** determines whether or not the basic update conditions are satisfied (step ST**22**).

[0279] When the terminal **20** has determined that the basic update conditions are not satisfied, the terminal **20** performs the following temporary update operation without performing the basic update process.

[0280] The terminal **20** determines whether or not the difference in height between the estimated height H**1** and the present height H**2** is less than the threshold value h (50 meters (m)) (step ST**32**).

[0281] When the terminal **20** has determined that the difference in height is less than the threshold value h, the termi-

nal **20** updates the height H**1** by averaging the estimated height H**1** and the height H**2** (step ST**33**). The step ST**33** exemplifies an updating step.

[0282] The terminal **20** increases the gain counter corresponding to the degree of positioning reliability (step ST**34**).

[0283] When the terminal **20** has determined that the difference in height is not less than the threshold value h in the step ST**32**, the terminal **20** updates the height H**1** by using the height H**2** as the estimated height H**1** (step ST**41**). The step ST**41** also exemplifies the updating step. It is considered that the estimated height H**1** is not reliable when the basic update conditions are not satisfied and the difference in height is equal to or greater than h (50 meters (m)) meters (m). Therefore, the terminal **20** updates the estimated height H**1** without taking the held estimated height H**1** into consideration.

[0284] The terminal **20** initializes the gain counter (step ST**42**). Specifically, the terminal **20** sets the gain counter to "3" (see FIG. **7**A).

[0285] When the terminal **20** has determined that the basic update conditions are satisfied in the step ST**22**, the terminal **20** changes the gain counter corresponding to the moving velocity (step ST**23**).

[0286] The terminal **20** performs adaptive control (step ST**24**).

[0287] The terminal **20** determines whether or not the positioning conditions when calculating the present height H**2** satisfy the gain temporary change conditions (step ST**201** in FIG. **12**).

[0288] When the terminal **20** has determined that the positioning conditions satisfy the gain temporary change conditions, the terminal **20** decreases the gain by one while maintaining the gain counter (step ST**202**).

[0289] The terminal **20** proceeds to a step ST**203**. When the terminal **20** has determined that the positioning conditions do not satisfy the gain temporary change conditions in the step ST**201**, the terminal **20** proceeds to the step ST**203**.

[0290] The terminal **20** determines whether or not the difference in height between the present height H**2** and the estimated height H**1** is equal to or greater than 1000 meters (m) (step ST**203**).

[0291] When the terminal **20** has determined that the difference in height is equal to or greater than 1000 meters (m), the terminal **20** determines whether or not the degree of positioning reliability is equal to or greater than the threshold value d**2** (step ST**204**). The degree of positioning reliability is the degree of positioning reliability the present two-dimensional positioning or three-dimensional positioning.

[0292] When the terminal **20** has determined that the degree of positioning reliability is equal to or greater than the threshold value d**2**, the terminal **20** add 1/64th of the difference in height to the estimated height H**1** (step ST**205**A).

[0293] When the terminal **20** has determined that the degree of positioning reliability is less than the threshold value d**2**, the terminal **20** adds 1/4th of the difference in height to the estimated height H**1** (step ST**205**B).

[0294] When the terminal **20** has determined that the difference in height is not equal to or greater than 1000 meters (m) in the step ST**203**, the terminal **20** determines whether or not the difference in height from the estimated height H**1** is equal to or greater than 500 meters (m) (step ST**206**).

[0295] When the terminal **20** has determined that the difference in height is equal to or greater than 500 meters (m), the terminal **20** determines whether or not the degree of positioning reliability is equal to or greater than the threshold value d**2** (step ST**207**).

[0296] When the terminal **20** has determined that the degree of positioning reliability is equal to or greater than the threshold value d**2**, the terminal **20** add 1/32nd of the difference in height to the estimated height H**1** (step ST**208**A).

[0297] When the terminal **20** has determined that the degree of positioning reliability is less than the threshold value d**2**, the terminal **20** adds half of the difference in height to the estimated height H**1** (step ST**208**B).

[0298] When the terminal **20** has determined that the difference in height is not equal to or greater than 500 meters (m) in the step ST**206**, the terminal **20** determines whether or not the difference in height from the estimated height H**1** is equal to or greater than 100 meters (m) (step ST**209**).

[0299] When the terminal **20** has determined that the difference in height is equal to or greater than 100 meters (m), the terminal **20** determines whether or not the degree of positioning reliability is equal to or greater than the threshold value d**2** (step ST**210**).

[0300] When the terminal **20** has determined that the degree of positioning reliability is equal to or greater than the threshold value d**2**, the terminal **20** add 1/16th of the difference in height to the estimated height H**1** (step ST**211**A).

[0301] When the terminal **20** has determined that the degree of positioning reliability is less than the threshold value d**2**, the terminal **20** adds half of the difference in height to the estimated height H**1** (step ST**211**B).

[0302] The terminal **20** updates the estimated height H**1** (step ST**212**). The step ST**212** also exemplifies an updating step.

[0303] When the positioning conditions satisfy the gain temporary change conditions, the terminal **20** decreases the gain while maintaining the gain counter, as described above.

[0304] In the step ST**212**, when the difference in height is equal to or greater than 100 meters (m), the estimated height H**1** is changed in advance corresponding to the difference in height and then updated. On the other hand, when the difference in height is less than 100 meters (m), the estimated height H**1** is updated without being changed in advance.

[0305] Therefore, the above steps allow accurate height information used for two-dimensional positioning to be acquired while reducing the storage load for holding height data and reducing the effects of poor positioning conditions during the preceding positioning. Moreover, the height information can be promptly updated.

[0306] (Program, Computer-Readable Recording Medium, and the Like)

[0307] A program for controlling a positioning device may be provided which causes a computer to execute the first height calculation step, the second height calculation step, the height selection step, the updating step, and the like of the above-described operation example.

[0308] A computer-readable recording medium having such a program for controlling a positioning device recorded thereon and the like may also be provided.

[0309] A program storage medium used to install the program for controlling a positioning device and the like in a computer to allow the program and the like to be executable by the computer may be implemented by a packaging medium such as a flexible disk such as a floppy disk (registered trademark), a compact disc read only memory (CD-ROM), a compact disc-recordable (CD-R), a compact disc-

rewritable (CD-RW), or a digital versatile disc (DVD), a semiconductor memory, a magnetic disk, or a magnetooptical disk in which the program is stored temporarily or permanently, or the like.

[0310] The invention is not limited to the above embodiments. The above embodiments may be configured in combination.

[0311] Although only some embodiments of the invention have been described above in detail, those skilled in the art would readily appreciate that many modifications are possible in the embodiments without materially departing from the novel teachings and advantages of the invention. Accordingly, such modifications are intended to be included within the scope of the invention.

What is claimed is:

1. A method at a positioning device, comprising:

calculating a first height by two-dimensional positioning based on a satellite signal and an estimated height indicating a distance from a center of the earth;

calculating a second height by three-dimensional positioning based on the satellite signal; and

updating the estimated height by using the first height or the second height.

2. The method of claim **1**, further comprising

determining a positioning environment, wherein

the updating the estimated height updates the estimated height based on the positing environment.

3. The method of claim **1**, wherein

the updating the estimated height updates the estimated height based on a movement state of the positioning device.

4. The method of claim **1**, wherein

the updating the estimated height updates the estimated height based on reliability of the two-dimensional positioning.

5. The method of claim **1**, further comprising

determining whether or not the estimated height satisfies a predetermined update condition including at least the number of updates of the estimated height, wherein

the updating the estimated height updates the estimated height while increasing weight of the estimated height when a difference between the estimated height and the first or second height is within a predetermined allowable range.

6. The method of claim **1**, further comprising

determining whether or not the estimated height satisfies a predetermined update condition including at least the number of updates the estimated height, wherein

the updating the estimated height updates the estimated height while reducing weight of the estimated height when a difference between the estimated height and the first or second height is not within a predetermined allowable range.

7. The method of claim **1**, wherein

the updating the estimated height updates the estimated height based on a difference between the estimated height and the first or second height, and a degree of positioning reliability.

8. A positioning device, comprising:

a first height calculator that calculates a first height by two-dimensional positioning based on a satellite signal and an estimated height indicating a distance from a center of the earth;

a second height calculator that calculates a second height by three-dimensional positioning based on the satellite signal; and

an estimated height updater that updates the estimated height by using the first height or the second height.

9. The positioning device of claim **8**, further comprising

an environment determiner that determined a positioning environment, wherein

the estimated height updater updates the estimated height based on the positioning environment.

10. The positioning device of claim **8**, wherein

the estimated height updater updates the estimated height based on a movement state of the positioning device.

11. The positioning device of claim **8**, wherein

the estimated height updater updates the estimated height based on reliability of the two-dimensional positioning.

12. The positioning device of claim **8**, further comprising

an update condition determiner that determines whether the estimated height satisfies a predetermined update condition including at least the number of updates of the estimated height, wherein

the estimated height updater updates the estimated height while increasing weight of the estimated height when a difference between the estimated height and the first or second height is within a predetermined allowable range.

13. The positioning device of claim **8**, further comprising

an update condition determiner that determines whether the estimated height satisfies a predetermined update condition including at least the number of updates of the estimated height, wherein

the estimated height updater updates the estimated height while reducing weight of the estimated height when a difference between the estimated height and the first or second height is not within a predetermined allowable range.

14. The positioning device of claim **12**, further comprising

a weight table storager that storages a weight table including the weight and a weight counter that designates the weight.

15. The positioning device of claim **8**, wherein

the estimated height updater updates the estimated height based on a difference between the estimated height and the first or second height, and a degree of positioning reliability.

16. The positioning device of claim **8**, further comprising

an estimated height storager that stores the estimated height.

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