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Denda

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(54) **MOVING AMOUNT ESTIMATING APPARATUS, AUTONOMOUS MOBILE BODY, AND MOVING AMOUNT ESTIMATING METHOD**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

5,995,883 A *	11/1999	Nishikado	G05D 1/0242	701/25
2005/0278068 A1*	12/2005	Hong	G05D 1/0253	700/259
2012/0219207 A1*	8/2012	Shin	G05D 1/0272	382/153

FOREIGN PATENT DOCUMENTS

CN	103926925 A	7/2014
JP	2004-318721 A	11/2004

(Continued)

OTHER PUBLICATIONS

Martinez et al., "Mobile Robot Motion Estimation by 2D Scan Matching with Genetic and Iterative Closest Point Algorithms", Journal of Field Robotics, vol. 23, No. 1, Jan. 1, 2006, 24 pages.

(Continued)

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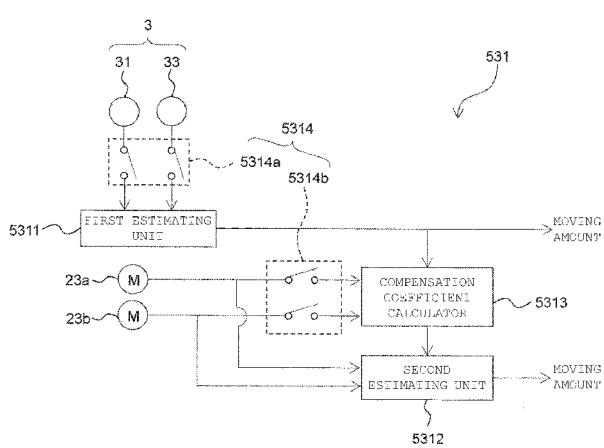
(57) **ABSTRACT**

A moving amount estimating apparatus includes a position data obtaining unit, a first estimating unit, and a second estimating unit. The position data obtaining unit obtains a plurality of position data used to form a projection object image before and after movement of a mobile body. The first estimating unit calculates a moving amount of a parallel movement and/or a rotational movement of second position data as a moving amount of a mobile body when a plurality of moving position data is calculated. A second estimating unit compensates for a wheel moving amount based on a comparison between a second reference moving amount based on a rotating amount of a wheel during a predetermined period and a first reference moving amount obtained by calculating the moving amount of the mobile body in the first estimating unit during the predetermined period, and estimates the moving amount of the mobile body.

9 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

B60W 40/101	(2012.01)
G01C 21/16	(2006.01)
G01S 7/48	(2006.01)
G01S 17/02	(2006.01)
G01S 17/89	(2006.01)
G05D 1/02	(2006.01)
G05D 1/00	(2006.01)
G01C 22/00	(2006.01)

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CPC ***G01C 21/165*** (2013.01); ***G01S 7/4808*** (2013.01); ***G01S 17/023*** (2013.01); ***G01S 17/89*** (2013.01); ***G05D 1/0088*** (2013.01); ***G05D 1/0272*** (2013.01); ***G05D 1/0274*** (2013.01); *B60W 2530/00* (2013.01); *B60W 2530/20* (2013.01); *B60W 2600/00* (2013.01); *G01C 22/00* (2013.01); *G05D 1/024* (2013.01)

(58) **Field of Classification Search**
CPC G01S 17/023; G01S 17/89; G01C 21/165; G05D 1/0088; G05D 1/0272
See application file for complete search history.

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2006-160116 A	6/2006
JP	2012-089174 A	5/2012

OTHER PUBLICATIONS

Lu et al., "Robot Pose Estimation in Unknown Environments by Matching 2D Range Scans" Proceedings of the Computer Society Conference on Computer Vision and Pattern Recognition, Jun. 21, 1994, pp. 935-938.

Surmann et al., "An Autonomous Mobile Robot with a 3D Laser Range Finder for 3D Exploration and Digitalization of Indoor Environments" Robotics and Autonomous Systems, vol. 45, No. 3-4, Dec. 31, 2003, pp. 181-198.

* cited by examiner

FIG. 1

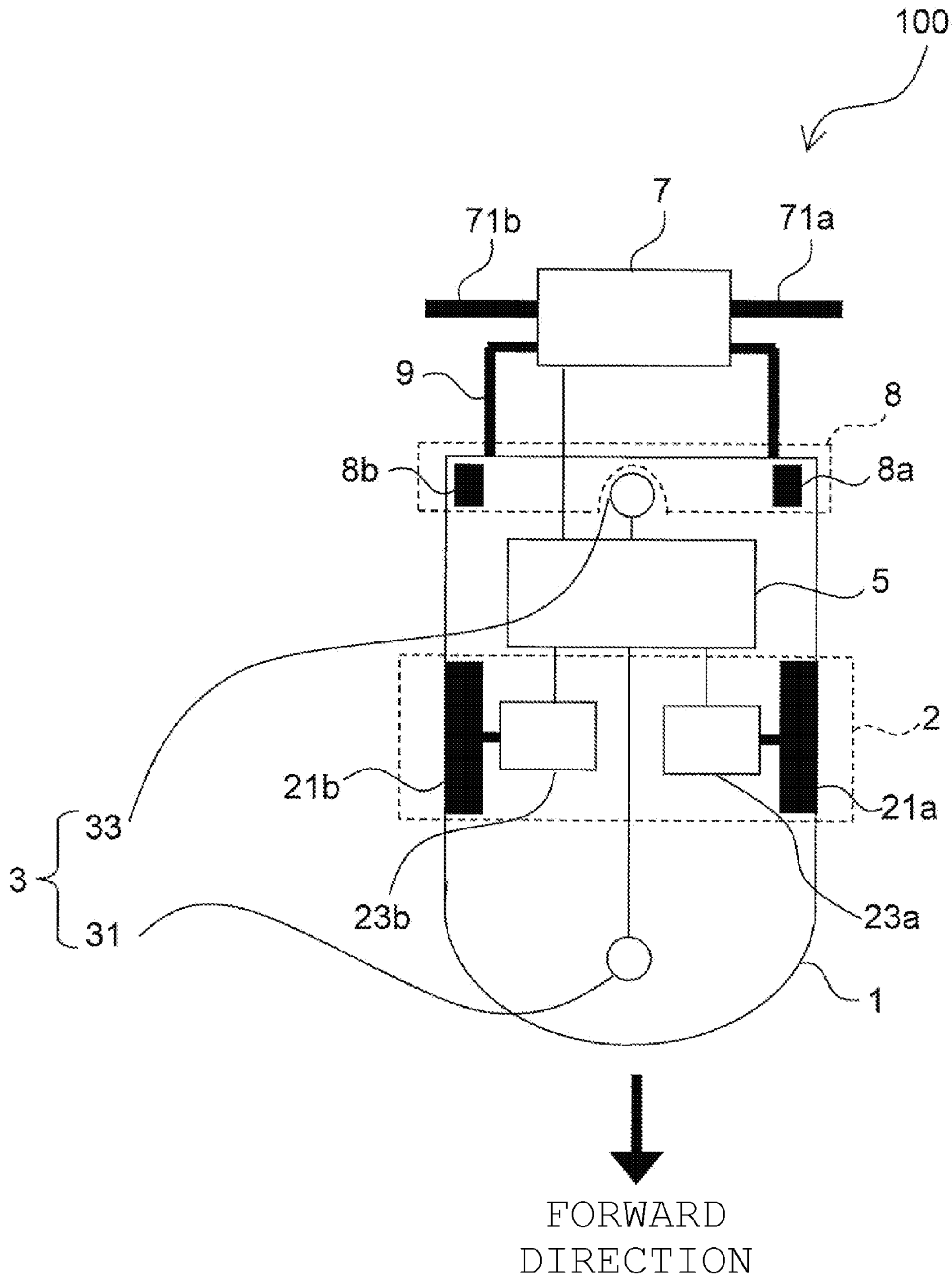

100
7
71b
71a
9
8
8b
8a
5
2
21b
21a
3
33
31
23b
23a
1
FORWARD DIRECTION

FIG. 2

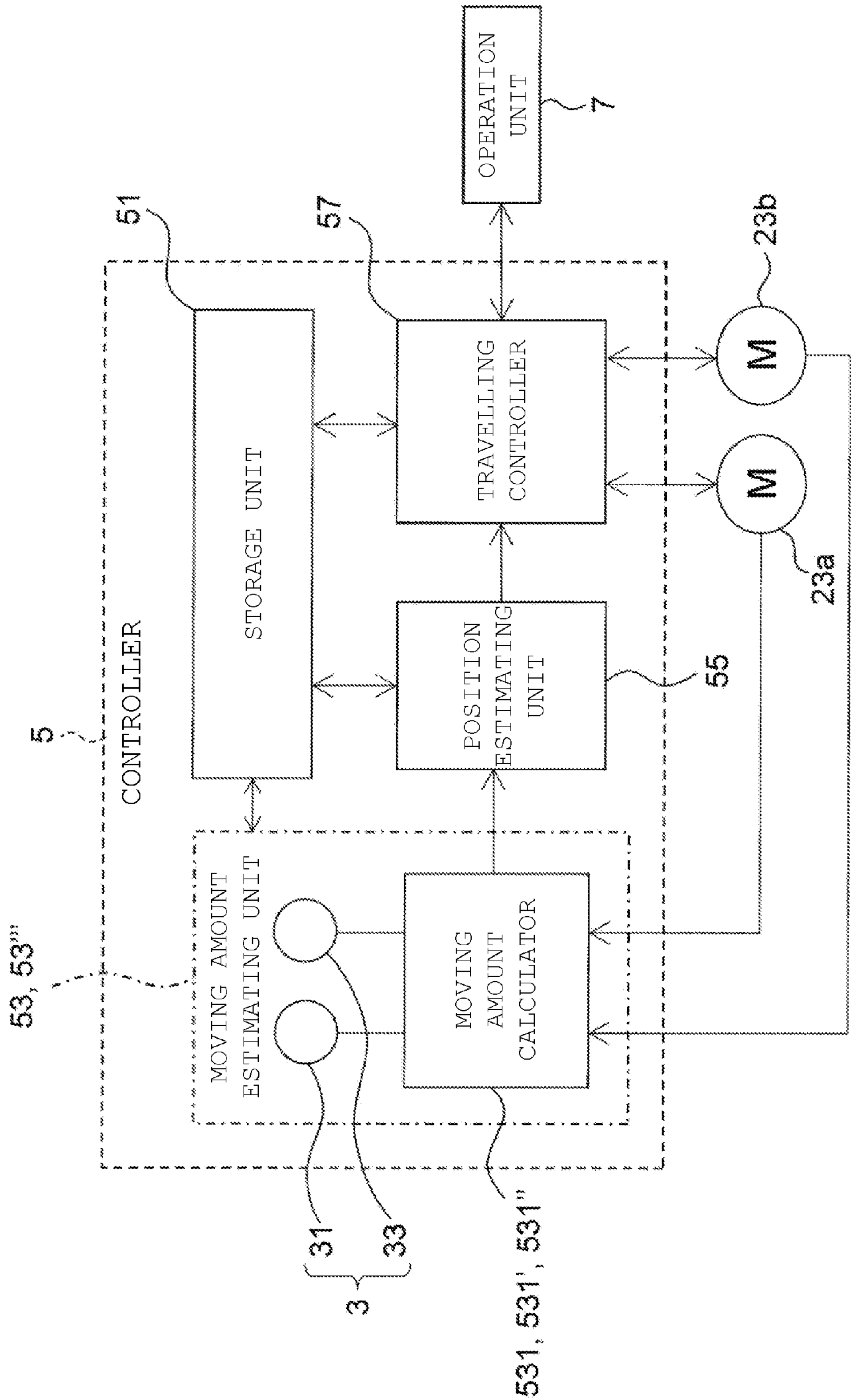
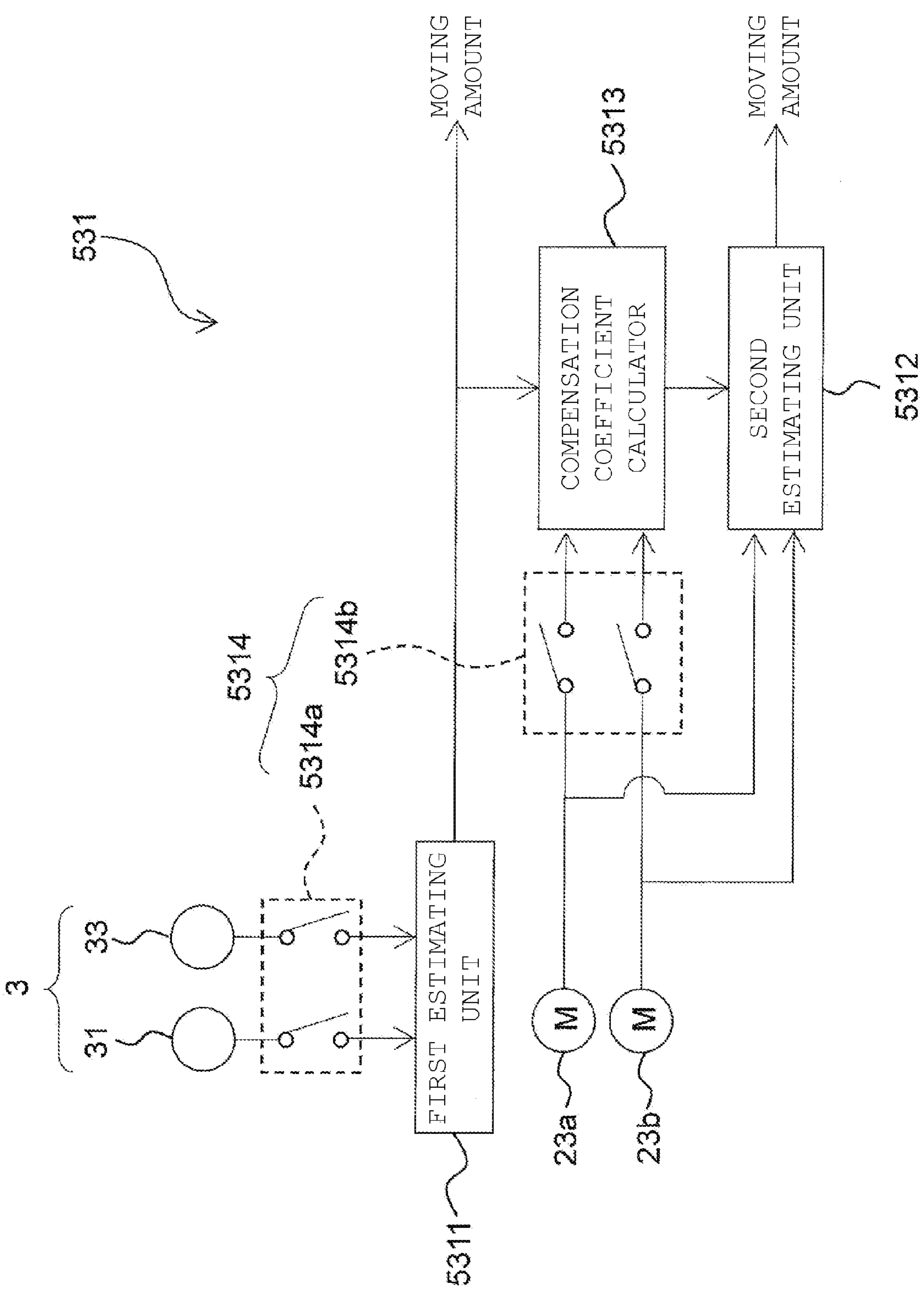

5
CONTROLLER
OPERATION UNIT
7
51
STORAGE UNIT
57
TRAVELLING CONTROLLER
POSITION ESTIMATING UNIT
55
M
M
23a
23b
53, 53''
MOVING AMOUNT ESTIMATING UNIT
MOVING AMOUNT CALCULATOR
31
33
3
531, 531', 531''

FIG. 3



531
3
31
33
5314
5314a
5314b
FIRST ESTIMATING UNIT
5311
MOVING AMOUNT
COMPENSATION COEFFICIENT CALCULATOR
5313
SECOND ESTIMATING UNIT
5312
MOVING AMOUNT
M
M
23a
23b

FIG. 4

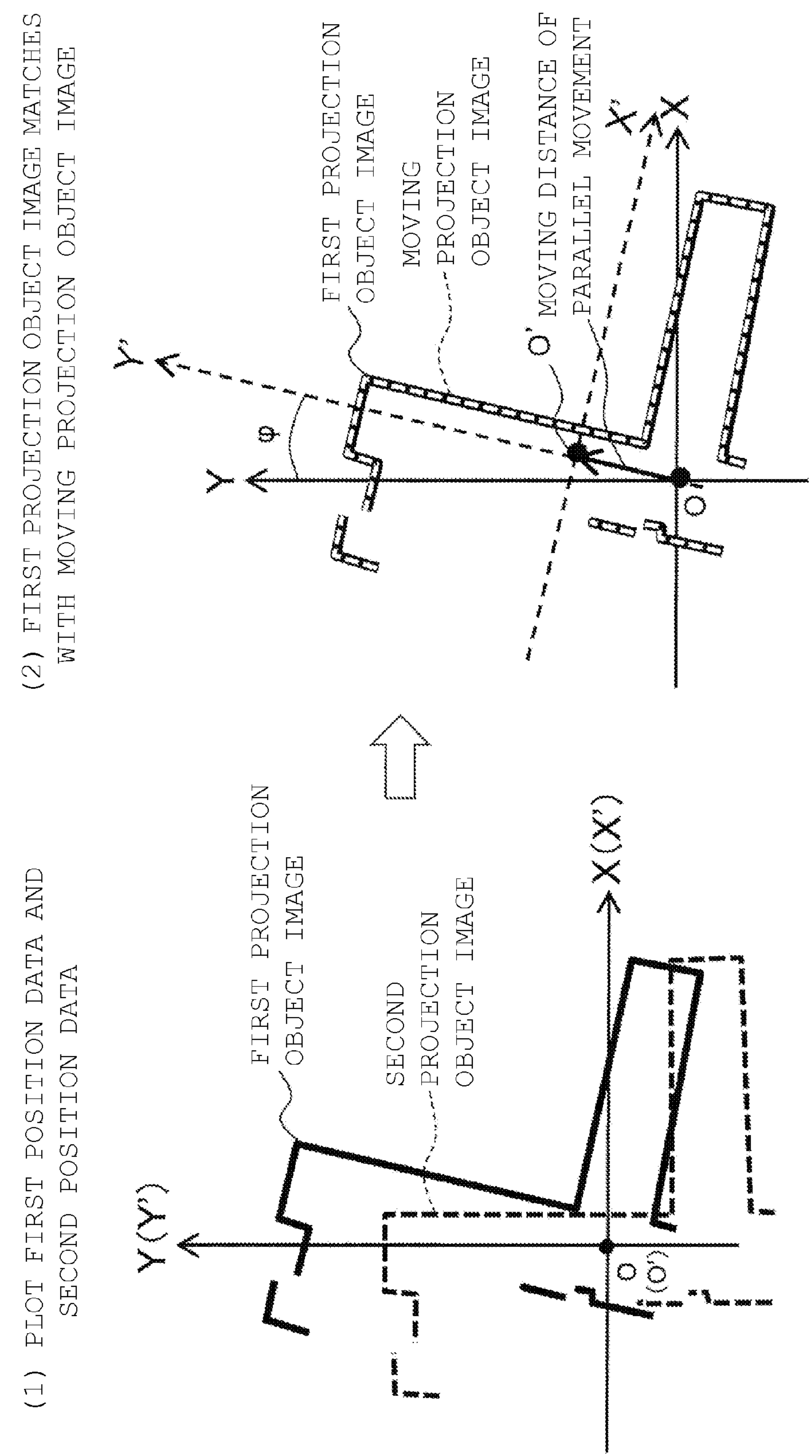

(1) PLOT FIRST POSITION DATA AND SECOND POSITION DATA
FIRST PROJECTION OBJECT IMAGE
SECOND PROJECTION OBJECT IMAGE
Y(Y')
X(X')
O (O')
(2) FIRST PROJECTION OBJECT IMAGE MATCHES WITH MOVING PROJECTION OBJECT IMAGE
FIRST PROJECTION OBJECT IMAGE
MOVING PROJECTION OBJECT IMAGE
MOVING DISTANCE OF PARALLEL MOVEMENT
Y'
Y
φ
O'
O
X'
X

FIG. 5

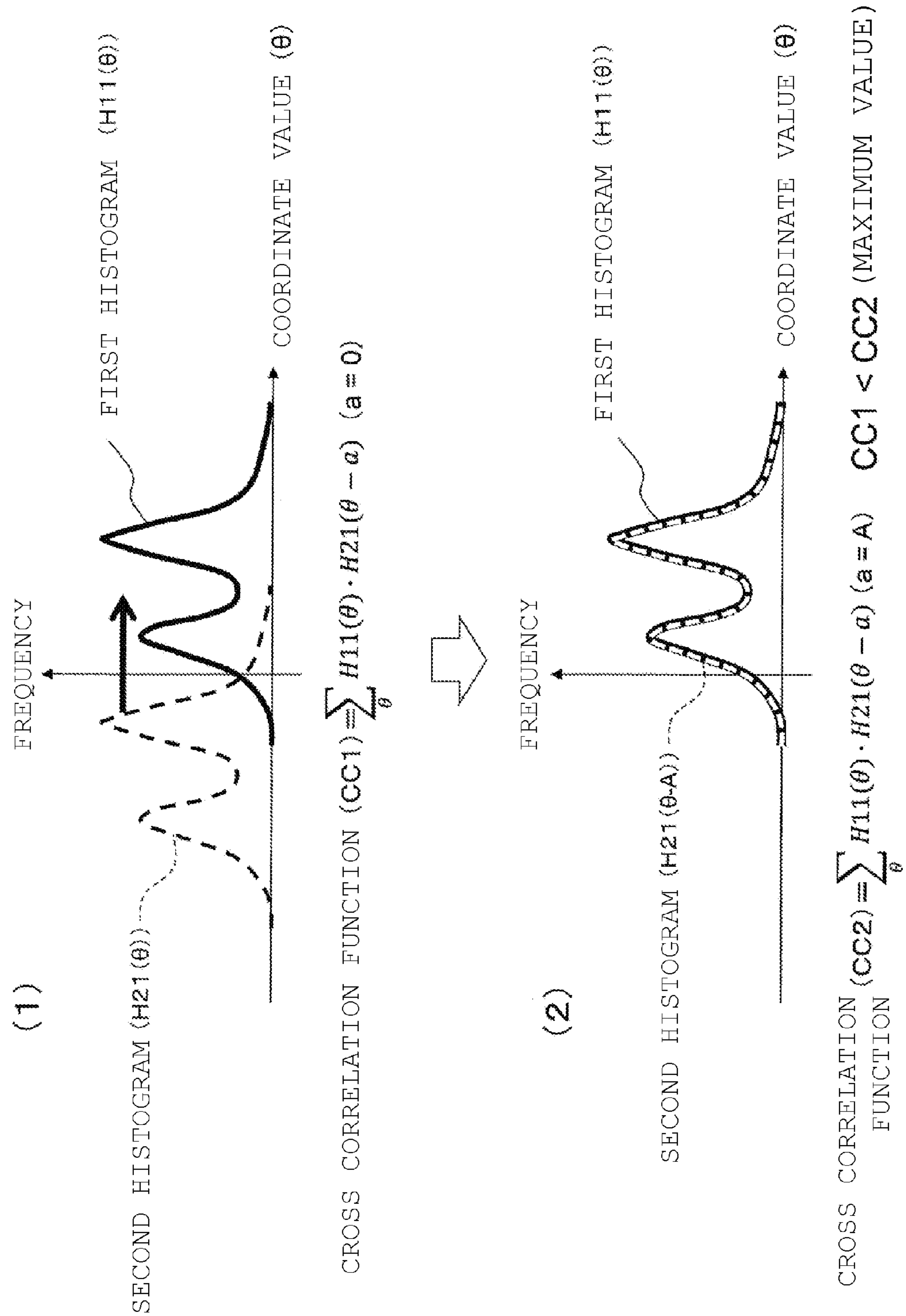

(1)
SECOND HISTOGRAM (H21(θ))
FIRST HISTOGRAM (H11(θ))
FREQUENCY
COORDINATE VALUE (θ)
CROSS CORRELATION FUNCTION (CC1) = $\sum_{\theta} H11(\theta) \cdot H21(\theta - a)$ (a = 0)
(2)
SECOND HISTOGRAM (H21(θ-A))
FIRST HISTOGRAM (H11(θ))
FREQUENCY
COORDINATE VALUE (θ)
CROSS CORRELATION FUNCTION (CC2) = $\sum_{\theta} H11(\theta) \cdot H21(\theta - a)$ (a = A)
CC1 < CC2 (MAXIMUM VALUE)

FIG. 6

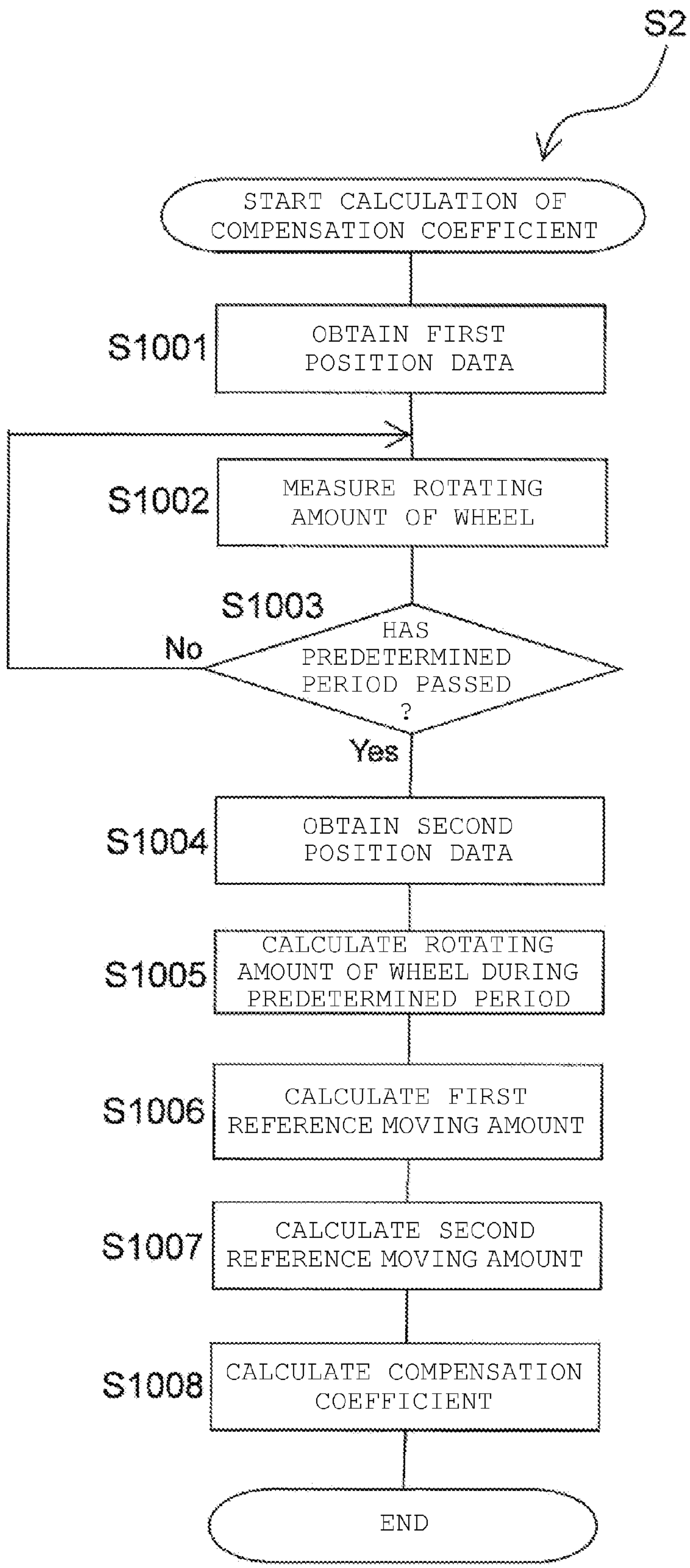

S2
START CALCULATION OF COMPENSATION COEFFICIENT
S1001
OBTAIN FIRST POSITION DATA
S1002
MEASURE ROTATING AMOUNT OF WHEEL
S1003
HAS PREDETERMINED PERIOD PASSED ?
No
Yes
S1004
OBTAIN SECOND POSITION DATA
S1005
CALCULATE ROTATING AMOUNT OF WHEEL DURING PREDETERMINED PERIOD
S1006
CALCULATE FIRST REFERENCE MOVING AMOUNT
S1007
CALCULATE SECOND REFERENCE MOVING AMOUNT
S1008
CALCULATE COMPENSATION COEFFICIENT
END

FIG. 7

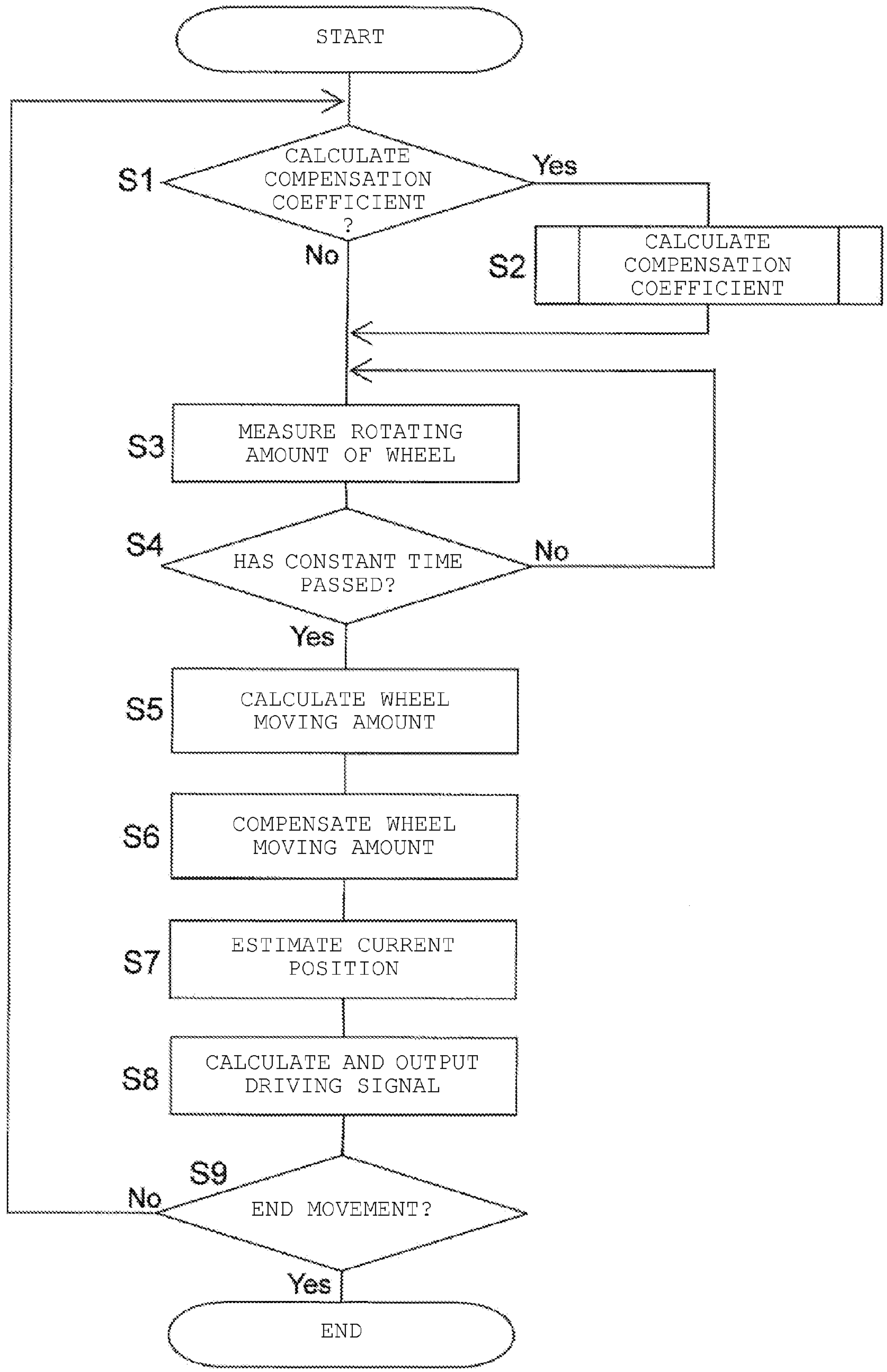
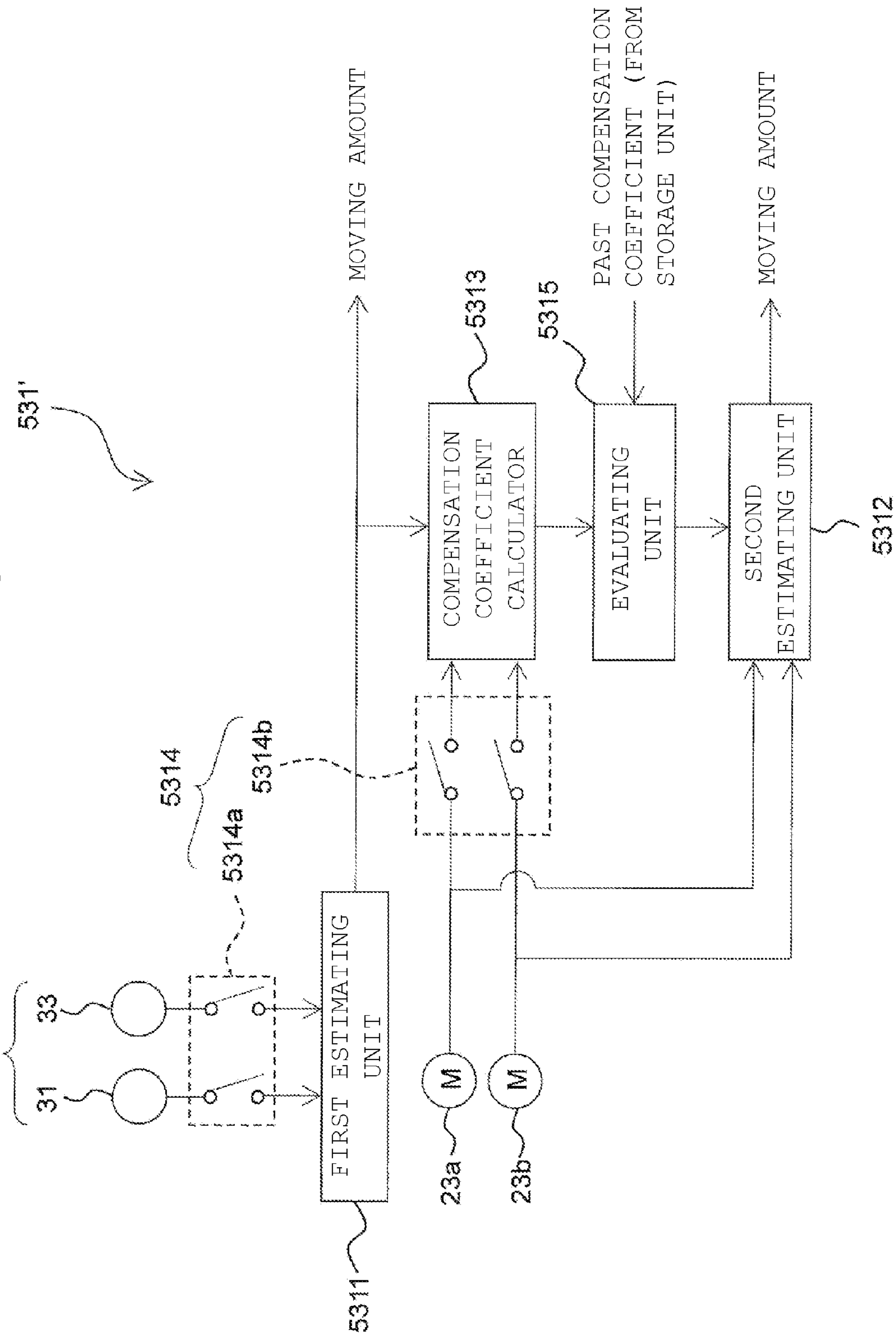
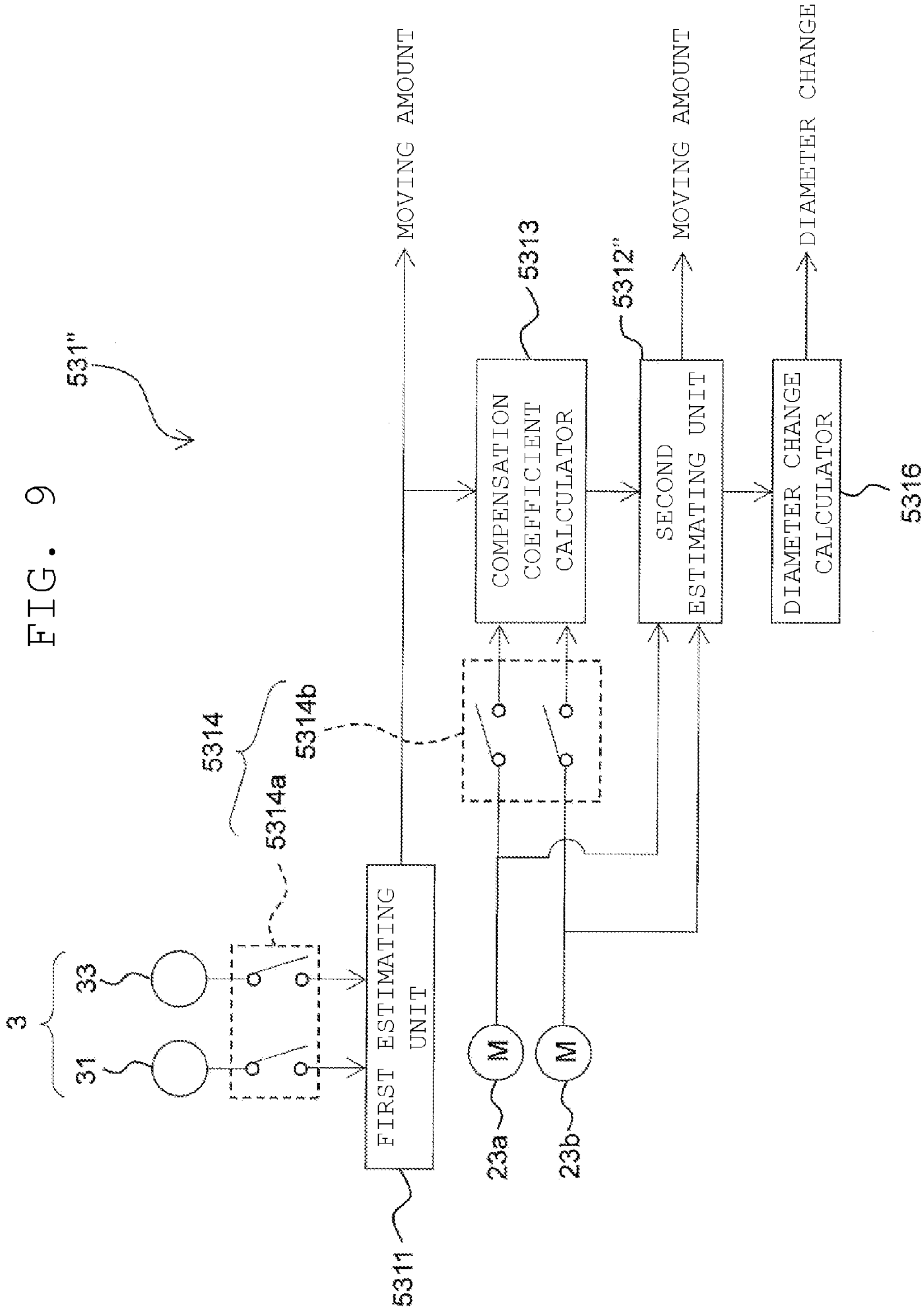

START
S1
CALCULATE COMPENSATION COEFFICIENT ?
Yes
No
S2
CALCULATE COMPENSATION COEFFICIENT
S3
MEASURE ROTATING AMOUNT OF WHEEL
S4
HAS CONSTANT TIME PASSED?
No
Yes
S5
CALCULATE WHEEL MOVING AMOUNT
S6
COMPENSATE WHEEL MOVING AMOUNT
S7
ESTIMATE CURRENT POSITION
S8
CALCULATE AND OUTPUT DRIVING SIGNAL
S9
END MOVEMENT?
No
Yes
END

FIG. 8


531'
3
31
33
5314
5314a
5314b
FIRST ESTIMATING UNIT
5311
M
M
23a
23b
MOVING AMOUNT
COMPENSATION COEFFICIENT CALCULATOR
5313
EVALUATING UNIT
5315
PAST COMPENSATION COEFFICIENT (FROM STORAGE UNIT)
SECOND ESTIMATING UNIT
5312
MOVING AMOUNT



531"
3
31
33
5314
5314a
5314b
FIRST ESTIMATING UNIT
5311
23a
23b
M
M
MOVING AMOUNT
COMPENSATION COEFFICIENT CALCULATOR
5313
SECOND ESTIMATING UNIT
5312"
MOVING AMOUNT
DIAMETER CHANGE CALCULATOR
5316
DIAMETER CHANGE

FIG. 9

MOVING AMOUNT ESTIMATING APPARATUS, AUTONOMOUS MOBILE BODY, AND MOVING AMOUNT ESTIMATING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. 119 to Japanese Patent Application No. 2014-241158, filed on Nov. 28, 2014, which application is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a moving amount estimating method for estimating a moving amount of a movable mobile body capable of being moved by rotation of a wheel, a moving amount estimating apparatus, and an autonomous mobile body including the moving amount estimating apparatus.

2. Description of the Related Art

Conventionally, a mobile body that can be moved in a predetermined space by rotation of a wheel is known. A travelling distance and/or a current position of such a mobile body are estimated based on a rotating amount of a wheel and/or a distance between the mobile body and an object present around the mobile body.

For example, JP 2004-318721 A discloses an autonomous travelling vehicle that includes an encoder and a distance measuring sensor and can travel according to rotational drive of a travelling wheel. In the autonomous travelling vehicle, a travelling distance of the autonomous travelling vehicle is calculated based on a rotation number measured by the encoder, and a distance between the autonomous travelling vehicle and a wall or an obstacle present around the vehicle is measured by the distance measuring sensor.

Further, the autonomous travelling vehicle described in JP 2004-318721 A compensates for a travelling distance per predetermined time calculated based on the rotation number of the travelling wheel using a change amount in the distance between the autonomous travelling vehicle and the wall or the obstacle measured by the distance measuring sensor per predetermined time. That is, in the conventional autonomous travelling vehicle, when the travelling distance calculated based on the rotation number of the travelling wheel includes an error caused by slippage between the travelling wheel and a floor, the error is compensated for according to the change amount of the distance per predetermined time measured by the distance measuring sensor.

However, the measurement error is not only included in the travelling distance calculated based on the rotation number (rotating amount) of the wheel measured by the encoder but also included in the distance between the autonomous travelling vehicle and an object such as an obstacle measured by the distance measuring sensor. For this reason, when a moving amount of the autonomous mobile body is small, the accuracy of the latter calculated travelling distance is below the accuracy of the former calculated travelling distance. In the autonomous travelling vehicle of JP 2004-318721 A, when an error is included in the distance measured by the distance measuring sensor and the moving amount of the autonomous mobile body is small, the travelling distance is transcribed into the travelling distance having lower accuracy.

SUMMARY OF THE INVENTION

According to a preferred embodiment of the present invention, in a mobile body capable of moving according to rotation of a wheel, compensation is accurately made so that a moving distance calculated based on a rotating amount of the wheel becomes a value close to an actual moving distance of the mobile body.

A plurality of aspects of various preferred embodiments of the present invention will be described below. These aspects can be arbitrarily combined as needed or desired.

According to one aspect of a preferred embodiment of the present invention, a moving amount estimating apparatus estimates a moving amount of a mobile body that is moved by rotation of a wheel and includes a position data obtaining unit, a first estimating unit, and a second estimating unit.

The position data obtaining unit obtains a plurality of position data used to form a projection object image. The projection object image is an image that is formed by plotting a plurality of position data on a predetermined coordinate and by projecting an object present around the mobile body onto the predetermined coordinate.

The first estimating unit calculates a moving amount when the mobile body moves. Specifically, the first estimating unit estimates a moving amount of parallel movement (translation) and/or a moving amount of a rotational movement (posture shift) of a plurality of second position data when a first projection object image matches with a moving projection object image as the moving amount when the mobile body moves.

The first projection object image is a projection object image to be formed by a plurality of first position data. The plurality of first position data includes a plurality of position data that is obtained one of before and after the movement of the mobile body.

The moving projection object image is a projection object image to be formed by a plurality of moving position data. The plurality of moving position data is a plurality of position data that is obtained by moving the plurality of second position data parallelly and/or rotationally on a predetermined coordinate. The plurality of second position data include a plurality of position data obtained the other of before and after the movement of the mobile body.

Note that, "the other of before and after the movement of the mobile body" means "after the movement of the mobile body" when the first position data is obtained before the movement of the mobile body, whereas "the other of before and after the movement of the mobile body" means "before the movement of the mobile body" when the first position data is obtained after the movement of the mobile body.

That is, the first estimating unit calculates a moving amount at times of the parallel movement and/or the rotational movement of the second position data as the moving amount when the mobile body moves, in order to obtain the plurality of moving position data used to form the moving projection object image to match with the first projection object image.

The second estimating unit compensates for a wheel moving amount of the wheel based on a comparison between a second reference moving amount and a first reference moving amount. Further, the second estimating unit estimates the compensated wheel moving amount as the moving amount of the mobile body. The wheel moving amount is a moving amount to be calculated based on the rotating amount of the wheel. The second reference moving amount is a wheel moving amount to be calculated based on the rotating amount of the wheel during a predetermined period of the movement of the mobile body. The first reference moving amount is a calculated value of the moving amount in the first estimating unit when the mobile body moves during the predetermined period.

In the moving amount estimating apparatus, when the mobile body moves during the predetermined period, the position data obtaining unit obtains a plurality of first position data one of before and after the movement of the mobile body, and obtains a plurality of second position data the other of before and after the movement of the mobile body.

After the plurality of first position data and the plurality of second position data are obtained, the first estimating unit calculates the first reference moving amount. Specifically, the first estimating unit moves the plurality of second position data parallelly and/or rotationally on a predetermined coordinate so as to calculate the moving position data. Thereafter, the first estimating unit determines whether the moving projection object image to be formed by the moving position data matches with the first projection object image to be formed by the first position data. When the determination is made that the moving projection object image matches with the first projection object image, the first estimating unit determines the moving amount of the parallel movement and/or the moving amount of the rotational movement when the second position data is moved parallelly and/or rotationally in order to obtain the moving position data forming the moving projection object image to match with the first projection object image as the first reference moving amount.

Further, the second reference moving amount is calculated based on the rotating amount of the wheel measured during the predetermined period.

After the first reference moving amount and the second reference moving amount are calculated, the second estimating unit compensates for the rotating amount of the wheel when the mobile body moves or the wheel moving amount of the mobile body, which is calculated based on the rotating amount of the wheel, based on a comparison between the second reference moving amount and the first reference moving amount. The second estimating unit estimates the compensated wheel moving amount as the moving amount of the mobile body.

In the moving amount estimating apparatus, the first reference moving amount to be used to compensate for the wheel moving amount is determined as the parallel moving amount and/or the moving amount of the rotational movement of the second position data when the moving position data is obtained such that the first projection object image matches with the moving projection object image. In other words, the moving amount when the projection object image to be formed by the plurality of second position data is moved so as to match with the first projection object image is determined as the first reference moving amount. Therefore, an influence of a measurement error included in the plurality of position data is significantly reduced or prevented, so that the first reference moving amount can be calculated as a value closer to the actual moving amount of the mobile body.

As a result, the second estimating unit compensates for the wheel moving amount more accurately using the first reference moving amount calculated with the influence of the measurement error included in the plurality of position data being reduced.

Further, the plurality of first position data and the plurality of second position data are obtained before and after the movement of the mobile body, respectively, namely, at a comparatively short time interval. This significantly reduces or eliminates problems such that an image present on the first projection object image to be formed by the plurality of first position data is not present on the projection object image (may also be referred to as a second projection object image) to be formed by the plurality of second position data, and on the contrary, an image that is not present on the first projection object image is likely to be present on the second projection object image (referred to as a change in ambient environment). As a result, the first estimating unit is able to prevent the first reference moving amount from being estimated by mistake due to the change in ambient environment and is able to calculate the first reference moving amount accurately. As a result, the wheel moving amount is compensated for more accurately.

The moving amount estimating apparatus may further include a compensation coefficient calculator. The compensation coefficient calculator calculates a compensation coefficient as a result of comparing the second reference moving amount with the first reference moving amount. The compensation coefficient is a coefficient to be calculated based on the first reference moving amount and the second reference moving amount. In this case, the second estimating unit compensates for the wheel moving amount using the compensation coefficient.

As a result, calculating frequencies of the second reference moving amount and the first reference moving amount is able to be significantly reduced. Further, even while the mobile body is moving at a location where the estimation of the position and the moving amount using the position data about a region where an object such as a wall is not present around the mobile body are difficult, the wheel moving amount is able to be compensated for more accurately. As a result, the moving amount of the mobile body is accurately estimated even in the above-described location based on the compensated wheel moving amount.

The moving amount estimating apparatus may further include an evaluating unit. The evaluating unit evaluates whether the compensation coefficient is appropriately calculated based on a result of comparing a past compensation coefficient and the compensation coefficient. The past compensation coefficient is a compensation coefficient calculated during a past period. The past period is a period before a predetermined period in which the compensation coefficient is calculated.

As a result, a determination is able to be made whether the compensation coefficient calculated at this time is calculated more reasonably based on characteristics of the wheel in comparison with the past compensation coefficient calculated at a previous time.

When the determination is made that the compensation coefficient is not appropriately calculated, the second estimating unit may use the past compensation coefficient as the compensation coefficient. As a result, when the compensation coefficient calculated at this time is calculated as an erroneous value, the second estimating unit avoids compensation of the wheel moving amount using the compensation coefficient calculated erroneously. That is, the wheel moving amount is prevented from being compensated for inaccurately.

The compensation coefficient calculator may calculate the compensation coefficient based on the compensation coefficient that is calculated based on the comparison between the first reference moving amount and the second reference moving amount and an updated coefficient having a predetermined value. As a result, a degree of variation caused by the compensation is controlled.

The second estimating unit may calculate the wheel moving amount based on a reference wheel diameter that is a predetermined diameter of the wheel and the rotating amount of the wheel. In this case, the second estimating unit compensates for the wheel moving amount using the compensation coefficient. That is, the second estimating unit compensates for the wheel moving amount, which is calculated by using the reference wheel diameter, using the compensation coefficient. As a result, the wheel moving amount is able to be compensated for by simpler calculation.

The second estimating unit may calculate a compensation wheel diameter. The compensation wheel diameter is calculated based on the reference wheel diameter and the compensation coefficient. In this case, the second estimating unit calculates the moving amount of the mobile body based on the compensation wheel diameter and the rotating amount of the wheel. That is, the second estimating unit compensates the reference wheel diameter using the compensation coefficient so as to calculate the compensation wheel diameter, and determines a value calculated based on the compensation wheel diameter and the rotating amount of the wheel as the moving amount of the mobile body. As a result, the moving amount of the mobile body to be calculated based on the rotating amount of the wheel is compensated for and simultaneously the wheel diameter is also compensated for.

The moving amount estimating apparatus may further include a diameter change calculator. The diameter change calculator calculates a change in a diameter of the wheel based on a comparison between the compensation wheel diameter and the reference wheel diameter. As a result, the change in the diameter of the wheel is able to be monitored.

The moving amount estimating apparatus may further include a compensation data obtaining command unit. The compensation data obtaining command unit specifies a predetermined period in which the first reference moving amount and the second reference moving amount are calculated. As a result, data used to calculate the first reference moving amount and the second reference moving amount is able to be obtained at timing at which both the plurality of position data and the rotating amount of the wheel is able to be obtained.

According to another aspect of various preferred embodiments of the present invention, an autonomous mobile body includes the moving amount estimating apparatus, a travelling unit, a position estimating unit, and a travelling controller. The travelling unit includes a wheel, and travels according to rotation of the wheel. That is, the travelling unit moves the autonomous mobile body according to the rotation of the wheel. The position estimating unit estimates a current position of autonomous mobile body based on a moving amount to be estimated by the moving amount estimating apparatus. The travelling controller controls the travelling unit so that the autonomous mobile body travels from the current position to a predetermined target position.

In the autonomous mobile body, the moving amount of the autonomous mobile body is estimated more accurately by the moving amount estimating apparatus. As a result, the position estimating unit of the autonomous mobile body is able to estimate a more accurate position of the autonomous mobile body. As a result, the travelling controller controls the travelling unit so that the autonomous mobile body is appropriately moved from the current position to the predetermined target position. That is, the autonomous mobile body is provided with the moving amount estimating apparatus so that the autonomous mobile body autonomously travels on an intended moving route accurately.

A moving amount estimating method according to still another aspect of various preferred embodiments of the present invention is a method for estimating the moving amount of the mobile body to be moved by the rotation of the wheel that includes a step of obtaining a plurality of position data forming a projection object image obtained by projecting an object present around a mobile body onto a predetermined coordinate before and after the mobile body moves during a predetermined period, a step of moving the plurality of second position data obtained any one of before and after the movement parallelly and/or rotationally on the predetermined coordinate so as to calculate the plurality of position data, a step of calculating a first reference moving amount based on a moving amount of a parallel movement and/or a moving amount of a rotational movement of the plurality of second position data when the plurality of moving position data is obtained such that a first projection object image to be formed by a plurality of first position data obtained the other of before and after the movement matches with a moving projection object image to be formed by the plurality of moving position data, a step of calculating a second reference moving amount based on a rotating amount of the wheel during the predetermined period, a step of compensating for a wheel moving amount, which is to be calculated based on the rotating amount of the wheel, based on a comparison between the second reference moving amount and the first reference moving amount, and a step of estimating the compensated wheel moving amount as the moving amount of the mobile body.

In the moving amount estimating method, the first reference moving amount to be used to compensate for the wheel moving amount is determined as the parallel moving amount and/or the wheel moving amount of the second position data when the moving position data is obtained such that the first projection object image matches with the moving projection object image. In other words, the moving amount, in which the projection object image to be formed by the plurality of second position data is moved so as to match with the first projection object image, is determined as the first reference moving amount. Therefore, an influence of a measurement error included in the plurality of position data is reduced, so that the first reference moving amount is able to be calculated as a value closer to the actual moving amount of the mobile body.

As a result, in the moving amount estimating method, the first reference moving amount, which is calculated by reducing the influence of the measurement error included in the plurality of position data, is used so that the wheel moving amount is compensated for more accurately.

A moving distance (the wheel moving amount) calculated based on the rotating amount of the wheel is compensated for accurately so as to be a value close to an actual moving distance of the mobile body.

The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating an entire configuration of an autonomous mobile body.

FIG. **2** is a diagram illustrating a configuration of a controller.

FIG. **3** is a diagram illustrating a configuration of a moving amount calculator according to a first preferred embodiment of the present invention.

FIG. **4** is a diagram schematically illustrating an ICP method.

FIG. **5** is a diagram schematically illustrating a histogram matching method.

FIG. **6** is a flowchart illustrating a method for calculating a compensation coefficient.

FIG. **7** is a flowchart illustrating an operation of the autonomous mobile body.

FIG. **8** is a diagram illustrating a configuration of a moving amount calculator according to a second preferred embodiment of the present invention.

FIG. **9** is a diagram illustrating a configuration of a moving amount calculator according to a third preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Preferred Embodiment

An autonomous mobile body according to a first preferred embodiment of the present invention is described below. The entire configuration of an autonomous mobile body **100** according to the first preferred embodiment is described with reference to FIG. **1**. The autonomous mobile body **100** according to this preferred embodiment is a mobile body that autonomously travels along a desired scheduled travelling route that is predetermined.

The autonomous mobile body **100** mainly includes a main body **1**, a travelling unit **2**, a position data obtaining unit **3** (e.g., a position data detector), and a controller **5**. The main body **1** constitutes a main body of the autonomous mobile body **100**.

The travelling unit **2** includes, as illustrated in FIG. **1**, wheels **21***a* and **21***b* and is installed near a center of a bottom of the main body **1** via motors **23***a* and **23***b* (described later) so that the wheels **21***a* and **21***b* make contact with a travelling surface such as a floor surface of a moving region. Further, the wheels **21***a* and **21***b* are mounted to output rotary shafts of the motors **23***a* and **23***b* provided to right and left sides of the main body **1**, respectively, so as to be rotatable around the output rotary shafts.

The motors **23***a* and **23***b* receive driving signals (described later) from the controller **5** and rotates the respective output rotary shafts based on the driving signals from the controller **5**. The wheels **21***a* and **21***b* rotate in rotating amounts and/or at rotating speeds according to the driving signals from the controller **5**. The travelling unit **2** moves the main body **1** (namely, the autonomous mobile body **100**) according to rotation of the wheels **21***a* and **21***b* that rotate at the rotating amounts and/or at the rotating speeds corresponding to the driving signals. Electric motors such as brushless motors can be used as the motors **23***a* and **23***b*, for example.

Further, devices, not illustrated in FIG. **1**, that measure rotating numbers (rotating amounts) of the output rotary shafts of the motors **23***a* and **23***b* are mounted to the output rotary shafts of the motors **23***a* and **23***b*, respectively. The rotating amounts of the output rotary shafts measured by the devices are then output to the controller **5**.

The controller **5** is configured or programmed to calculate the rotating amounts of the wheels **21***a* and **21***b* based on the rotating amounts of the output rotary shafts of the motors **23***a* and **23***b*. Encoders or the like can be used as the devices that measure the rotating amounts of the output rotary shafts of the motors **23***a* and **23***b*. When the rotating amounts of the output rotary shafts are measured by, for example, incremental type encoders, the rotating amounts of the output rotary shafts are able to be measured as pulse numbers per predetermined time included in pulse signals to be output from the encoders.

The position data obtaining unit **3** obtains a plurality of position data. The plurality of position data forms an image obtained by projecting an object such as an obstacle or a wall present around the autonomous mobile body **100** onto a predetermined coordinate (hereinafter, referred to as an "object projection image"). That is, the plurality of position data is defined as a coordinate value on the predetermined coordinate.

The plurality of position data that can form the object projection image can be obtained by using a laser range finder (LRF) or the like as the position data obtaining unit **3**. A device such as a ToF (Time of Flight) camera that measures a distance from the device to a certain object present around the device can also be used as the position data obtaining unit **3**, for example.

In this preferred embodiment, the laser range finder is preferably used as the position data obtaining unit **3**, but in this case, the plurality of position data is obtained as, for example, two-dimensional data including a distance from the autonomous mobile body **100** to a predetermined portion of the object (for example, a portion of a surface of the object reflecting a signal output from the laser range finder) and an angle representing a direction from the autonomous mobile body **100** where the portion of the object is present.

Further, when the ToF camera is used as the position data obtaining unit **3**, the plurality of position data is obtained as, for example, three-dimensional data including a distance from the autonomous mobile body **100** to a predetermined portion of the object (for example, a portion of a surface of the object reflecting a signal output from the ToF camera), an angle in a horizontal direction on a two-dimensional plane and an angle in a vertical direction representing directions from the autonomous mobile body **100** where the portion of the object is present.

When the moving amount of the autonomous mobile body **100** is estimated based on the plurality of position data as described later, the moving amount may be estimated by using position data having the obtained distance and angle as coordinate values. In this case, the position data is defined as the coordinate values of the distance from the autonomous mobile body **100** to the object and the angle with respect to the autonomous mobile body **100** at which the object is present.

Alternatively, the moving amount of the autonomous mobile body **100** may be estimated by using new position data obtained by performing suitable coordinate conversion on the obtained position data. For example, the obtained position data is able to be converted by the coordinate conversion into position data having coordinate values of coordinates representing a relative position with respect to the autonomous mobile body **100** (for example, an X-Y coordinate in two dimensions, and an X-Y-Z coordinate in three dimensions) (one example of the predetermined coordinate).

In this preferred embodiment, the obtained position data is defined as the coordinate value of the X-Y coordinate, so that the moving amount of the autonomous mobile body **100** is estimated. As a result, the actual moving amount of the autonomous mobile body **100** in the moving region is able to be directly estimated.

The position data to be obtained in the position data obtaining unit **3** is coordinate value data that is not influenced by a change in diameters caused by use of the wheels **21***a* and **21***b*. In this preferred embodiment, therefore, the plurality of position data obtained in the position data obtaining unit **3** are used to calculate a moving amount that is closer to the actual moving amount of the autonomous mobile body **100** within the moving region.

As illustrated in FIG. **1**, the position data obtaining unit **3** preferably includes a forward data obtaining unit **31** and a backward data obtaining unit **33**. The forward data obtaining unit **31** is mounted to a front portion of the autonomous mobile body **100**, and is able to obtain position data of an object present in front of the autonomous mobile body **100**. On the other hand, the backward data obtaining unit **33** is mounted to a back portion of the autonomous mobile body **100** in an advancing direction, and is able to obtain position data from an object present at the back of the autonomous mobile body **100**.

In this preferred embodiment, a position data obtainable range of the forward data obtaining unit **31** is wider than a position data obtainable range of the backward data obtaining unit **33**. In this preferred embodiment, for example, preferably the backward data obtaining unit **33** is able to detect an object present within an about 180° range of the back of the autonomous mobile body **100** within an approximate 10 m radius from a center of the backward data obtaining unit **33**, whereas the forward data obtaining unit **31** is able to detect an object present within an about 270° range of the front of the autonomous mobile body **100** within an approximate 30 m radius from a center of the forward data obtaining unit **31**.

In such a manner, the position data obtaining unit **3** is able to detect an object present within a wider range from the center of the autonomous mobile body **100** (particularly, in front of the autonomous mobile body **100**). An object detecting range of the forward data obtaining unit **31** and an object detecting range of the backward data obtaining unit **33** are not limited to the above-described detecting ranges, and suitable ranges can be set as needed.

In this preferred embodiment, the forward data obtaining unit **31** and/or the backward data obtaining unit **33** preferably are mounted above (the front and the back of) the main body **1**. As a result, when an object placed on a floor surface in the moving region frequently moves (for example, when layouts of shelves and signboards are frequently changed as in large retailers), a temporal change in a projection object image to be formed by the plurality of position data obtained by the forward data obtaining unit **31** and the backward data obtaining unit **33** (particularly, a change such that an object present at a certain time is not present at another time) can be reduced.

In the conventional technique, when an object placed in the moving region is frequently moved, a projection object image to be formed by the plurality of position data obtained before the autonomous mobile body **100** moves is greatly different from a projection object image to be formed by the plurality of position data obtained after the movement in some cases. When the projection object images are different before and after the movement, it is difficult to match one of the projection object images before and after the movement with the other of the projection object images, even if one of the projection object images before and after the movement is moved in any way. In this case, it is difficult to estimate the moving amount of the autonomous mobile body **100** using the plurality of position data.

In the conventional technique, when the projection object images before and after the movement of the autonomous mobile body **100** are greatly different from each other and the determination is made that the moved projection object image matches with the projection object image as a reference, the moving amount, to be estimated from the moving amount of the moved projection object image, of the autonomous mobile body **100** is very different from the actual moving amount of the autonomous mobile body **100** in some cases. That is, a great error is occasionally caused between the moving amount, which is estimated based on the plurality of position data, of the autonomous mobile body **100** and the actual moving amount of the autonomous mobile body **100**.

In order to solve these problems, in this preferred embodiment, the forward data obtaining unit **31** and/or the backward data obtaining unit **33** are provided above the main body **1** (for example, a position exceeding heights of a person's head or store shelves), so that a probability of detecting an object to be frequently moved is reduced. As a result, the moving amount of the autonomous mobile body **100** is able to be estimated accurately by using the plurality of position data obtained by the forward data obtaining unit **31** and the backward data obtaining unit **33** (the position data obtaining unit **3**) without causing a great error.

The controller **5** controls the travelling unit **2**. Further, the controller **5** estimates the position of the autonomous mobile body **100** within the moving region in order to control the travelling unit **2**.

When the autonomous mobile body **100** has the above configuration, the autonomous mobile body **100** can autonomously move along the predetermined travelling route while estimating a position of the mobile body **100** within the moving region.

As illustrated in FIG. **1**, the autonomous mobile body **100** according to the first preferred embodiment further includes an operation unit **7** mounted to the main body **1** via a mounting member **9**. As illustrated in FIG. **1**, the operation unit **7** includes turnable operation handles **71***a* and **71***b*, and operating amounts (turning amounts) of the operation handles **71***a* and **71***b* is able to be output to the controller **5**. As a result, the controller **5** calculates driving signals that control the motors **23***a* and **23***b* in accordance with the operating amounts of the operation handles **71***a* and **71***b*.

Provision of the operation unit **7** to the autonomous mobile body **100** enables an operator to operate the autonomous mobile body **100**. Specifically, the operator turns the operation handles **71***a* and **71***b* and adjusts the turning amounts and the rotating speeds of the wheels **21***a* and **21***b*, so as to be capable of operating the autonomous mobile body **100**.

Further, the controller **5** is able to estimate a position of the main body of the autonomous mobile body **100** in the moving region. For this reason, when the operator operates the autonomous mobile body **100** using the operation unit **7**, the position of the autonomous mobile body **100** is estimated at predetermined time intervals, and the estimated position is stored in a storage unit **51** or the like. As a result, the operation of the autonomous mobile body **100** performed by the operator is presented as the predetermined travelling route to the autonomous mobile body **100** (the controller **5**).

A method for presenting the travelling route to the autonomous mobile body **100** is not limited to a method for estimating and storing the position of the autonomous mobile body **100** while the operator is operating the autonomous mobile body **100** using the operation unit **7**. For example, the travelling route can be presented to the autonomous mobile body **100** also by directly operating (or directly inputting) values of (a plurality of) coordinate points on data where the coordinate points on a moving coordinate representing the moving region are stored. Alternatively, the travelling route can be presented to the autonomous mobile body **100** by another method for specifying a position of the autonomous mobile body **100** in the moving range (a coordinate value of the moving coordinate).

Further, the autonomous mobile body **100** of the first preferred embodiment preferably further includes a safety wheel unit **8**. The safety wheel unit **8** includes two safety wheels **8***a* and **8***b*. The two safety wheels **8***a* and **8***b* are mounted to a rear bottom surface of the main body **1** so as to be each independently rotatable. The provision of the safety wheel unit **8** enables the autonomous mobile body **100** to move stably and smoothly.

The entire configuration of the controller **5** is described below with reference to FIG. **2**. The controller **5** can be realized by a microcomputer system or the like that includes a CPU (Central Processing Unit), a hard disc device, a ROM (Read Only Memory), a RAM (Random Access Memory), a storage device constituted by a storage medium reading device, and an interface that converts a signal. Further, some of or all of functions of the respective units of the controller **5** to be described below may be realized as at least one program that is executable by the CPU of the controller **5**, for example. The at least one program may be stored in a storage device of a microcomputer. Alternatively, some of or all of the functions of the respective units of the controller **5** may be realized by a custom IC, circuitry, or the like, for example.

Further, the controller **5** may be configured by a plurality of microcomputer systems. For example, a moving amount estimating unit **53** (one example of a moving amount estimating apparatus), described later, a travelling controller **57**, and other components of the controller **5** may be configured by the individual microcomputer systems.

The controller **5** preferably includes the storage unit **51**, the moving amount estimating unit **53**, a position estimating unit **55** (e.g., a position estimator), and the travelling controller **57**. The storage unit **51** corresponds to at least a portion of a storage region of the storage device constituting the controller **5**. The storage unit **51** stores information relating to the moving route necessary for autonomous movement of the autonomous mobile body **100** in the moving region. Examples of the information relating to the moving route are data representing coordinate values on the moving coordinate corresponding to positions in the moving region where the autonomous mobile body **100** should pass during the autonomous movement, and map information representing the moving region (may also be referred to as a global map or an environmental map). In addition, the storage unit **51** stores various setting values necessary for the operation of the autonomous mobile body **100**.

The moving amount estimating unit **53** estimates a moving distance of the autonomous mobile body **100**. For this reason, the moving amount estimating unit **53** includes a moving amount calculator **531**. The moving amount calculator **531** calculates a distance (moving amount) along which the autonomous mobile body **100** moves based on the plurality of position data obtained by the position data obtaining unit **3** and the rotating amounts of the wheels **21***a* and **21***b* measured by the encoders or the like of the motors **23***a* and **23***b* of the travelling unit **2**.

The position estimating unit **55** estimates a present position of the autonomous mobile body **100** in the moving region. In this preferred embodiment, the position estimating unit **55** estimates a current position of the autonomous mobile body **100** using SLAM (Simultaneous Localization and Mapping) method based on a map matching result of map information representing a position of an object such as a wall or an obstacle around the autonomous mobile body **100** present at the current position (local map), and map information representing the moving region (the entire moving region or a portion of the moving region including at least a region where the autonomous mobile body **100** moves) stored in advance (the global map, the environmental map).

Specifically, the position estimating unit **55** generates a plurality of "temporary current positions" calculated by adding a predetermined error to the moving amount estimated by the moving amount estimating unit **53**. The temporary current positions are able to be calculated by, for example, adding the moving amount to which the error is added to the position of the autonomous mobile body **100** estimated before the movement.

The local map is generated by using the plurality of position data obtained on the temporary current position through the position data obtaining unit **3** for each of the temporary current positions. Thereafter, the position estimating unit **55** estimates a temporary current position where the local map, which matches the most with the environmental map, in the plurality of generated local maps is generated as the current position of the autonomous mobile body **100**.

When the plurality of position data cannot be obtained because the autonomous mobile body **100** moves on a region where a wall or the like is not present, or when a temporary change hardly occurs in the map information because the autonomous mobile body **100** moves on a linear passage without branching, the position estimating unit **55** adds a moving amount input from the moving amount estimating unit **53** to a position estimated before the movement so as to be capable of estimating the current position of the autonomous mobile body **100**.

Further, when the operator operates the autonomous mobile body **100** using the operation unit **7**, the position estimating unit **55** may estimate the position of the autonomous mobile body **100** at predetermined time intervals (for example, per control cycle) using the above method and store information about the estimated position (coordinate values or the like) in the storage unit **51**. Accordingly, the position estimating unit **55** can store the moving operation of the autonomous mobile body **100** to be performed by the operator in the storage unit **51**.

The position estimating unit **55** may update the environmental map to be stored in the storage unit **51** using the local map generated in the current position. As a result, even when the position of an obstacle or the like is changed in the moving region, a new environmental map after the position of the obstacle is changed can be created to be stored.

When the autonomous mobile body **100** autonomously moves, the travelling controller **57** controls the travelling unit **2** so that the autonomous mobile body **100** travels from the current position to a predetermined target position included in the predetermined moving route stored in the storage unit **51** (for example, the route on which the autonomous mobile body **100** is moved by the moving operation performed by the operator).

The travelling controller **57** outputs the driving signals individually to the motors **23***a* and **23***b*. That is, the motors **23***a* and **23***b* can rotate at different rotating speeds. For example, when the autonomous mobile body **100** is desired to be moved straight, the motors **23***a* and **23***b* are rotated at the same rotating speeds. On the other hand, when the motors **23***a* and **23***b* are rotated at different rotating speeds, the autonomous mobile body **100** can make rotary motions (a right turn and a left turn).

A travelling unit, in which the two wheels **21***a* and **21***b* are rotated to travel individually by the motors **23***a* and **23***b* like the travelling unit **2** illustrated in FIG. **1**, is referred to also as a "differential two-wheel" travelling unit.

Further, the travelling controller **57** is able to input turning amounts (operating amounts) of the operation handles **71***a* and **71***b* from the operation unit **7**, and calculate the driving signals based on the input turning amounts so as to output the respective driving signals to the motors **23***a* and **23***b*. As a result, the autonomous mobile body **100** is able to be operated by the operator who operates the operation handles **71***a* and **71***b*.

A control device or the like using a feedback control theory can be used as the travelling controller **57**. When the control device adopting the feedback control theory is used as the travelling controller **57**, the travelling controller **57** is able to input pulse signals from the encoders mounted to the output rotary shafts of the motors **23***a* and **23***b* and is able to control the rotating numbers of the motors **23***a* and **23***b* in accordance with a control command.

The configuration of the moving amount calculator **531** according to the first preferred embodiment is described below with reference to FIG. **3**. The moving amount calculator **531** of the first preferred embodiment preferably includes a first estimating unit **5311** (e.g., a first estimator) and a second estimating unit **5312** (e.g., a second estimator).

The first estimating unit **5311** calculates a moving amount when the autonomous mobile body **100** moves using the plurality of position data obtained by the position data obtaining unit **3**. Specifically, the first estimating unit **5311** calculates the moving amount of the autonomous mobile body **100** based on the plurality of position data obtained before the movement of the autonomous mobile body **100** and the plurality of position data obtained after the movement.

The second estimating unit **5312** estimates the moving amount of the autonomous mobile body **100** based on a wheel moving amount to be calculated based on the rotating amounts of the wheels **21***a* and **21***b* during the movement of the autonomous mobile body **100**. The wheel moving amount is able to be calculated based on reference wheel circumferential lengths (obtained by multiplying reference wheel diameters of the wheels **21***a* and **21***b* (reference wheel diameters) by π) and the measured rotating amounts of the wheels **21***a* and **21***b*.

Further, the second estimating unit **5312** compensates for the wheel moving amount based on a comparison between a second reference moving amount and a first reference moving amount. The second reference moving amount is a moving amount to be calculated based on the rotating amounts of the wheels **21***a* and **21***b* during a predetermined period in which the autonomous mobile body **100** moves. Further, the first reference moving amount is an estimated value of the moving amount of the autonomous mobile body **100** during the predetermined period. The estimated value is estimated in the first estimating unit **5311** by using the plurality of position data obtained before and after the predetermined period.

The second estimating unit **5312** estimates the compensated wheel moving amount as the actual moving amount of the autonomous mobile body **100**. As a result, the wheel moving amount is able to be compensated for more accurately by using the first reference moving amount estimated by using the plurality of position data.

In this preferred embodiment, the second estimating unit **5312** compensates for the calculated wheel moving amount using a compensation coefficient (described later) calculated in advance. For example, the second estimating unit **5312** multiplies the wheel moving amount by a compensation coefficient so as to be capable of compensating for the wheel moving amount. The compensation is made by using the compensation coefficient calculated in advance, so that calculating (measuring) frequencies of the second reference moving amount and the first reference moving amount to be used to compensate for the wheel moving amount are able to be reduced.

When the wheel moving amount is compensated for by using the compensation coefficient calculated in advance, the second estimating unit **5312** is able to estimate the moving amount of the autonomous mobile body **100** accurately based on the rotating amounts of the wheels **21***a* and **21***b* even while the autonomous mobile body **100** is moving in a location where the estimation of the position and the moving amount using the position data is difficult. Examples of such a location are a location where position data of a wide moving region where a wall or an obstacle is not present cannot be obtained, and a location where a change in a projection object image of a passage or the like defined by a linear wall hardly occurs.

The moving amount calculator **531** of this preferred embodiment further includes a compensation coefficient calculator **5313**. The compensation coefficient calculator **5313** inputs the rotating amounts of the wheels **21***a* and **21***b* therein from the encoders of the motors **23***a* and **23***b* via a second obtaining command unit **5314***b* (described later) so as to calculate the second reference moving amount.

Further, the compensation coefficient calculator **5313** calculates the compensation coefficient as a result of comparing the second reference moving amount with the first reference moving amount based on the calculated second reference moving amount and the first reference moving amount input from the first estimating unit **5311**. The compensation coefficient is able to be calculated as, for example, a ratio between the first reference moving amount and the second reference moving amount.

The compensation coefficient calculator **5313** stores the calculated compensation coefficient in the storage unit **51** or the like. The storage of the calculated compensation coefficient enables the second estimating unit **5312** to compensate for the wheel moving amount with reference to the compensation coefficient even when the second reference moving amount and the first reference moving amount are not calculated.

The moving amount calculator **531** of this preferred embodiment further includes a compensation data obtaining command unit **5314**. The compensation data obtaining command unit **5314** determines the predetermined period. In this preferred embodiment, the compensation data obtaining command unit **5314** includes a first obtaining command unit **5314***a* and the second obtaining command unit **5314***b*.

The first obtaining command unit **5314***a* determines an input period of the position data to be input from the position data obtaining unit **3** into the first estimating unit **5311**. Specifically, the first obtaining command unit **5314***a* connects the first estimating unit **5311** with the position data obtaining unit **3** only for the predetermined period. As a result, the first estimating unit **5311** is able to obtain the plurality of position data at start timing and end timing of the predetermined period.

On the other hand, the second obtaining command unit **5314***b* determines an input period of signals (pulse signals) to be input from the encoders of the motors **23***a* and **23***b* into the compensation coefficient calculator **5313**. Specifically, the second obtaining command unit **5314***b* connects the encoders of the motors **23***a* and **23***b* with the compensation coefficient calculator **5313** only for the predetermined period. As a result, the compensation coefficient calculator **5313** is able to obtain the rotating amounts of the wheels **21***a* and **21***b* during the predetermined period.

For example, when the first obtaining command unit **5314***a* does not input position data because the position data obtaining unit **3** does not (cannot) detect an object around the autonomous mobile body **100**, the first obtaining command unit **5314***a* and the second obtaining command unit **5314***b* may block the input of the position data into the first estimating unit **5311** and/or inputs of the pulse signals from the encoders of the motors **23***a* and **23***b* into the compensation coefficient calculator **5313**.

Alternatively, the first obtaining command unit **5314***a* and the second obtaining command unit **5314***b* may operate independently or in synchronization with each other. Further, not limited to the time when the first obtaining command unit **5314***a* does not input position data, but it may repeat the input and blocking of the signals per set predetermined time. The first obtaining command unit **5314***a* and the second obtaining command unit **5314***b* can input and block the signals at suitable timings as necessary.

The operation of the autonomous mobile body **100** of this preferred embodiment is described below. The method for calculating the moving amount of the autonomous mobile body **100** in the first estimating unit **5311** is described first. As described above, the first estimating unit **5311** estimates the moving amount of the autonomous mobile body **100** using the plurality of position data obtained before and after the movement of the autonomous mobile body **100** (for example, a plurality of first position data obtained before the movement of the autonomous mobile body **100**, and a plurality of second position data obtained after the movement).

The method for estimating the moving amount of the autonomous mobile body **100** using the plurality of position data is a method for, when either the plurality of first position data or the plurality of second position data is moved on a predetermined coordinate and is matched with the plurality of position data that is not moved, estimating the moving amount based on the plurality of position data that is moved. Such a moving amount estimating method includes an ICP (Iterative Closest Point) method and a histogram matching method.

The moving amount estimating method using the ICP method is described. The ICP method is a method for estimating the moving amount by searching for moving amounts of the plurality of second position data so that a first projection object image to be formed by the plurality of position data not to be moved (first position data) matches with a projection object image (a moving projection object image) to be formed by the plurality of position data to be moved (second position data).

Specifically, the moving amounts of the plurality of second position data are calculated so that the first projection object image matches with the second projection object image.

A distance between the moving projection object image to be formed by the plurality of moving position data to be calculated by moving the plurality of second position data and the first projection object image to be formed by the plurality of first position data is a calculated first. For example, a distance, which is calculated by summing up a predetermined number (for example, the number of the first position data) of distances between the one first position data and (one or a plurality of) moving position data corresponding to the one first position data, is able to be calculated as a distance between the moving projection object image and the first projection object image.

A determination is made whether the moving projection object image matches with the first projection object image based on a comparison of the distance between the moving projection object image and the first projection object image with a predetermined threshold. For example, when the distance between the two projection object images is the predetermined threshold or less, the determination is able to be made that the two projection object images match with each other. When the determination is made that the two projection object images match with each other, the moving amount of the plurality of moving position data forming the moving projection object image this time from the plurality of second position data is estimated as the moving amount of the autonomous mobile body **100**.

On the other hand, when the two projection object images do not match with each other, the plurality of moving position data (the second position data) at this time is further moved, and a determination is made whether the distance between the two projection object images is calculated and the two projection object images match with each other. As a result, the moving position data (the second position data) are repeatedly moved until the determination is made that the two projection object images match with each other. The moving amount of the moving position data (the second position data) when the two projection object images do not match with each other can be determined based on, for example, a comparison of a result of calculating the distance between the two projection object images at this time with a result of calculating the distance between the two projection object images at a previous time.

The method for estimating the moving amount using the ICP method is schematically illustrated in FIG. **4**. The plurality of first position data and the plurality of second position data are plotted on an X-Y coordinate system so that a first origin O as an origin of the first position data matches with a second origin O' as an origin of the second position data. In this case, the first projection object image (a solid line) and the second projection object image (a dotted line) are formed on the same coordinate as illustrated in (**1**) of FIG. **4**. When the plurality of second position data (the moving position data) is moved parallelly from this state, the second origin O' is moved. When the plurality of second position data is movement rotationally, a coordinate (an X'-Y' coordinate) for defining the second position data tilts with respect to a coordinate (an X-Y coordinate) for defining the first position data.

As illustrated in (**2**) of FIG. **4**, a distance between the first origin O and the second origin O' when the first projection object image matches with the moving projection object image corresponds to the moving distance of the parallel movement of the autonomous mobile body **100** (namely, an X coordinate of the second origin O' on the X-Y coordinate after the movement corresponds to the moving amount in an X direction, and a Y coordinate of the second origin O' on the X-Y coordinate after the movement corresponds to the moving amount in a Y direction). Further, a tilt angle of each axis (dotted lines) on the X'-Y' coordinate with respect to each corresponding axis (solid lines) on the X-Y coordinate corresponds to a change in a posture angle of the autonomous mobile body **100**.

The moving amount estimating method using the histogram matching method is described below. The histogram matching method is, as illustrated in FIG. **5**, a method for estimating an amount of shift of a first histogram or a second histogram from an original histogram as the moving amount of the autonomous mobile body **100** when a matching degree between the first histogram to be generated from coordinate values of the plurality of first position data and the second histogram to be generated from coordinate values of the plurality of second position data has a maximum value. FIG. **5** is a diagram schematically illustrating the moving amount estimating method using the histogram matching method. In this preferred embodiment, a value of a cross correlation function between the first histogram and the second histogram is calculated as the matching degree, but not limited to this, a value of a normalized cross correlation function or a value of a zero-mean normalized cross correlation function between the first histogram and the second histogram may be calculated as the matching degree.

Specifically, the moving amount is estimated as follows. A histogram representing an appearance frequency of an angle θ with respect to one axis (any axis) on the coordinate for defining position data of a straight line that connects one position data and position data adjacent to this one position data is generated first.

The cross correlation function of the two histograms calculated for the angle θ is, then, calculated as a value obtained by adding θ that enables H**11** (θ)*H**21** (θ−a) to be obtained (also said as an integral value of H**11** (θ)*H**21** (θ−a) with respect to θ). The value "a" corresponds to the shift amount of the histogram illustrated in FIG. **5**.

Thereafter, the value "a" that makes the cross correlation function be the maximum value is calculated as a moving amount of the angle θ. The moving amount of the angle θ is a moving amount corresponding to a change in the posture angle of the autonomous mobile body **100**.

Specifically, for example, in the calculated cross correlation function, the values of the cross correlation function are calculated for the values "a" to be obtained, and the value "a" when a largest value in the calculated values of the cross correlation function is estimated as the change in the posture angle of the autonomous mobile body **100**.

A histogram representing an appearance frequency of the coordinate value of the position data is generated for each of the first position data and the position data (the moving position data) that is obtained by rotating the second position data by using the rotational moving amount (the change in the posture angle) calculated in the above manner, specifically for respective coordinate axes (the X axis and the Y axis in two dimensions, and the X axis, the Y axis and the Z axis in three dimension) of coordinates for defining the position data.

As a result, two histograms (H**12**(X), H**13**(Y)) (in two dimensions) are further generated for the first position data. On the other hand, two histograms (H**22**(X), H**23**(Y)) (in two dimensions) are generated for the moving position data.

Further, similarly to the above, a shift amount of the histogram for making a cross correlation function between the two histograms H**12**(X) and H**22**(X) representing the appearance frequency of the coordinate value of the X axis becomes the maximum value is estimated as the moving amount of the autonomous mobile body **100** in the X axial direction, and a shift amount of the histogram for making a cross correlation function between the two histograms H**13**(Y) and H**23**(Y) representing the appearance frequency of the coordinate value in the Y axis becomes the maximum value is estimated as the moving amount of the autonomous mobile body **100** in a Y axial direction.

Shifting of one histogram so that the two histograms representing the appearance frequencies of the coordinate values of the coordinate axes match with each other corresponds to moving of the plurality of second position data so that the second projection object image matches with the first projection object image as illustrated in FIG. **4**. Specifically, the moving amount of the angle θ corresponds to the moving amount of the rotational movement such that the plurality of second position data matches with the plurality of first position data. The moving amount in the X axial direction and the moving amount in the Y axial direction correspond to the moving amount of the parallel movement so that the plurality of second position data matches with the plurality of first position data.

Further, it is also said that shifting of the second histogram corresponds to moving of the plurality of second position data and calculation of the plurality of position data.

In such a manner, the first estimating unit **5311** estimates the moving amount of the autonomous mobile body **100** based on a value (the distance between the two projection object images in the ICP method and the cross correlation function between the two histograms in the histogram matching method) that is calculated by using the plurality of position data according to the ICP method or the histogram matching method. As a result, even when (some of) the position data obtained by the position data obtaining unit **3** include a measurement error (caused by a noise or the like), the first estimating unit **5311** is able to reduce an influence of the measurement error and estimate the moving amount.

Further, the plurality of first position data and the plurality of second position data are obtained before and after the movement of the mobile body, respectively, namely, at a comparatively short time interval. For this reason, an environmental change problem that arises when an image present on the first projection object image is not present on the second projection object image or on the contrary an image not present on the first projection object image is present on the second projection object image hardly arises in the first estimating unit **5311**.

The environmental change problem is a problem that arises when the moving amount and the position are estimated based on matching of map information obtained by the position data obtaining unit **3** using the SLAM method that estimates the moving amount and the position of the autonomous mobile body **100** based on a result of matching a local map with a global map.

For example, when an object present on the global map is not present on the local map and/or an object not present on the global map is present on the local map, even if a determination is made that the two maps (map information) match with each other in calculation, the estimated moving amount and position are very different from the actual moving amount and position in some cases.

When the first position data and the second position data are obtained at a short period, a change in ambient environment hardly occurs between the two position data. As a result, the first estimating unit **5311** is able to be estimate the moving amount accurately.

The method for calculating the compensation coefficient in the compensation coefficient calculator **5313** is described below with reference to FIG. **6**. The compensation coefficient calculator **5313** calculates the compensation coefficient based on a comparison of a calculated value of the second reference moving amount calculated based on the rotating amounts of the wheels **21***a* and **21***b* at a predetermined period (to be determined by, for example, the position data and/or the input period of the rotating amounts of the wheels **21***a* and **21***b* in the compensation data obtaining command unit **5314**) with a calculated value of the moving amount of the autonomous mobile body **100** in the first estimating unit **5311** at the predetermined period (namely, the first reference moving amount).

Specifically, the first obtaining command unit **5314***a* first can input position data into the first estimating unit **5311**, and the second obtaining command unit **5314***b* can input pulse signals from the encoders of the motors **23***a* and **23***b* into the compensation coefficient calculator **5313** (step S**1001**).

At this time, the first estimating unit **5311** obtains the plurality of position data (corresponding to the first position data) before the movement of the autonomous mobile body **100** (at start timing of the predetermined period) from the position data obtaining unit **3** so as to store the plurality of position data in the storage unit **51**.

On the other hand, the compensation coefficient calculator **5313** starts to input the pulse signals from the encoders of the motors **23***a* and **23***b*, and starts to measure the rotating amounts of the wheels **21***a* and **21***b* (step S**1002**).

Thereafter, the first estimating unit **5311** and the compensation coefficient calculator **5313** start to input the position data into the first estimating unit **5311**, and determines whether a predetermined period passes after the rotating amounts of the wheels **21***a* and **21***b* (the pulse signals from the encoders) start to be input into the compensation coefficient calculator **5313** (step S**1003**).

When the predetermined period does not pass after the first position data starts to be obtained and the rotating amounts of the wheels **21***a* and **21***b* start to be input ("No" at step S**1003**), a process to calculate the compensation coefficient returns to step S**1002** so that the compensation coefficient calculator **5313** continues to measure the rotating amounts of the wheels **21***a* and **21***b*.

On the other hand, when the determination is made that the predetermined period passes after the first position data starts to be obtained and the rotating amounts of the wheels **21***a* and **21***b* start to be input ("Yes" at step S**1003**), the first estimating unit **5311** obtains the plurality of position data (corresponding to the second position data) from the position data obtaining unit **3** so as to store the plurality of position data in the storage unit **51** (step S**1004**).

Thereafter, the first obtaining command unit **5314***a* of the compensation data obtaining command unit **5314** blocks the input of the position data into the first estimating unit **5311**. Further, the second obtaining command unit **5314***b* blocks the input of the pulse signals from the encoders of the motors **23***a* and **23***b* into the compensation coefficient calculator **5313**. As a result, a predetermined period to calculate the first reference moving amount and the second reference moving amount is determined.

After the pulse signals from the encoders of the motors **23***a* and **23***b* are blocked, the compensation coefficient calculator **5313** calculates the rotating amounts of the wheels **21***a* and **21***b* for the predetermined period based on pulse numbers included in the pulse signals for the predetermined period (step S**1005**). Specifically, the rotating amounts of the wheels **21***a* and **21***b* are able to be calculated based on a ratio between the pulse numbers in the pulse signals measured for the predetermined period and pulse numbers included in the pulse signals when the wheels **21***a* and **21***b* rotate once (a certain value that can be determined in advance).

Thereafter, the first estimating unit **5311** calculates the first reference moving amount as the moving amount in which the autonomous mobile body **100** moves for the predetermined period using the plurality of obtained first position data and the plurality of obtained second position data according to the method for estimating the moving amount of the autonomous mobile body **100** (step S**1006**).

On the other hand, the compensation coefficient calculator **5313** calculates the moving amount of the autonomous mobile body **100** moved by the wheels **21***a* and **21***b* during the predetermined period (the wheel moving amount) as the second reference moving amount based on the rotating amounts of the wheels **21***a* and **21***b* during the predetermined period (step S**1007**).

Specifically, the compensation coefficient calculator **5313** calculates the second reference moving amount based on the rotating amounts of the wheels **21***a* and **21***b* during the predetermined period and the predetermined circumferential lengths of the diameters of the wheels **21***a* and **21***b* (the reference wheel diameters) (namely, $\pi\times$ the reference wheel diameters).

The reference wheel diameters are diameters of the wheels **21***a* and **21***b* at a certain predetermined time point. The reference wheel diameters are, for example, the wheel diameters of the wheels **21***a* and **21***b* before use. It is, therefore, discovered that the second reference moving amount is the moving amount based on the hypothetical rotating amounts of the wheels **21***a* and **21***b* that are calculated without considering the diameter change of the wheels **21***a* and **21***b*.

After the first reference moving amount and the second reference moving amount are calculated, the compensation coefficient calculator **5313** calculates the compensation coefficient (step S**1008**).

In this preferred embodiment, the compensation coefficient calculator **5313** calculates a ratio between the first reference moving amount and the second reference moving amount (the first reference moving amount/the second reference moving amount) as the compensation coefficient. After the compensation coefficient is calculated, the compensation coefficient calculator **5313** stores the calculated compensation coefficient in the storage unit **51**, and ends the process to calculate the compensation coefficient.

When the compensation coefficient calculator **5313** calculates the compensation coefficient using the first reference moving amount and the second reference moving amount so as to store it in the storage unit **51**, the calculating frequencies of the second reference moving amount and the first reference moving amount are able to be reduced.

As an alternative preferred embodiment of the compensation coefficient calculating method, the compensation coefficient calculator **5313** may further multiply the ratio between the first reference moving amount and the second reference moving amount by an updated coefficient and use the obtained value as the compensation coefficient. In this case, the updated coefficient has a predetermined positive value smaller than 1, for example. As a result, the ratio between the first reference moving amount and the second reference moving amount changes more greatly than the ratio at the previous calculation, so that the moving amount obtained by the rotation of the wheels **21***a* and **21***b* is able to be prevented from being calculated as values that greatly vary by each calculation. The updated coefficient may have a predetermined positive value larger than 1. In this case, even when the ratio between the first reference moving amount and the second reference moving amount does not change more greatly than the ratio at the previous calculation, the moving amount can be compensated for more greatly (actively).

A specific operation of the autonomous mobile body **100** according to this preferred embodiment is described below with reference to FIG. **7**. The following description is made on an operation when the autonomous mobile body **100** autonomously moves to a final target point while passing through a plurality of predetermined target points stored in the storage unit **51**.

When the autonomous movement of the autonomous mobile body **100** starts, the compensation coefficient calculator **5313** checks if the compensation coefficient is to be calculated (step S**1**).

For example, when the compensation data obtaining command unit **5314** determines that the position data can be obtained and that the compensation coefficient can be calculated ("Yes" at step S**1**), the compensation coefficient calculator **5313** executes steps S**1001** to S**1008** so as to calculate the compensation coefficient (step S**2**). After the compensation coefficient calculator **5313** calculates the compensation coefficient, the autonomous moving process goes to step S**3**.

When the compensation coefficient is calculated at step S**2**, the compensation coefficient calculator **5313** adds a sum of calculated values of the moving amount of the autonomous mobile body **100** to date in the first estimating unit **5311** and the moving amount calculated from a sum of the rotating numbers of the wheels **21***a* and **21***b* to date to the first reference moving amount and the second reference moving amount calculated at steps S**1006** and S**1007** for the predetermined period. The added values may be used as a new first reference moving amount and a new second reference moving amount.

On the other hand, for example, when the compensation data obtaining command unit **5314** determines that position data cannot be obtained and the compensation coefficient cannot be calculated, or that the compensation coefficient is not to be calculated ("No" at step S**1**), the autonomous moving process goes to step S**3**.

After the compensation coefficient is calculated or the determination is made that the compensation coefficient cannot be calculated (or the compensation coefficient is not to be calculated), the second estimating unit **5312** starts to input pulse signals from the encoders of the motors **23***a* and **23***b*. That is, the second estimating unit **5312** starts to measure the rotating amounts of the wheels **21***a* and **21***b* (step S**3**).

When the position data obtaining unit **3** obtains the position data at step S**3** (namely, the first obtaining command unit **5314***a* can input the position data into the first estimating unit **5311**), the first estimating unit **5311** may obtain the plurality of position data.

During the measurement of the rotating amounts of the wheels **21***a* and **21***b*, the second estimating unit **5312** determines whether a constant time passes after the measurement of the rotating amounts of the wheels **21***a* and **21***b* starts (step S**4**). The constant time is a timing, for example, at which the estimation of the current position, described later, is necessary (for example, a control cycle) that can be arbitrarily determined as necessary.

When the constant time does not pass after the measurement of the rotating amounts of the wheels **21***a* and **21***b* starts ("No" at step S**4**), the autonomous moving process returns to step S**3**, so that the rotating amounts of the wheels **21***a* and **21***b* continue to be measured.

On the other hand, when the determination is made that the constant time passes after the measurement of the rotating amounts of the wheels **21***a* and **21***b* starts ("Yes" at step S**4**), the second estimating unit **5312** calculates the moving amount of the autonomous mobile body **100** (the wheel moving amount) based on the rotating amounts of the wheels **21***a* and **21***b* (step S**5**).

Specifically, the second estimating unit **5312** first calculates the rotating amounts of the wheels **21***a* and **21***b* until the passage of the constant time after the start of the measurement of the rotating amounts based on the pulse numbers of the pulse signals input for the period. The second estimating unit **5312**, then, calculates the wheel moving amount based on the calculated rotating amounts of the wheels **21***a* and **21***b*, and peripheral lengths of the reference wheel diameters of the wheels **21***a* and **21***b* (namely, $\pi\times$ the reference wheel diameters).

When the first estimating unit **5311** obtains the plurality of position data at step S**3**, the first estimating unit **5311** may obtain the plurality of position data from the position data obtaining unit **3** also at step S**5**. In this case, the first estimating unit **5311** may calculate the moving amount of the autonomous mobile body **100** for the constant time using the plurality of position data obtained before and after the movement of the autonomous mobile body **100** for the constant time according to the moving amount calculating method in the first estimating unit **5311**, described above.

After the wheel moving amount is calculated, the second estimating unit **5312** compensates for the wheel moving amount calculated at step S**5** (step S**6**). In this preferred embodiment, the second estimating unit **5312** multiplies the wheel moving amount calculated at step S**5** by the compensation coefficient calculated at step S**2** so as to compensate for the wheel moving amount. As a result, the second estimating unit **5312** compensates for the wheel moving amount calculated at step S**5** based on the comparison between the second reference moving amount and the first reference moving amount calculated at step S**2**, so as to be capable of calculating the compensated wheel moving amount as the moving amount of the autonomous mobile body **100** moved for the constant time.

After the moving amount of the autonomous mobile body **100** moved for the constant time is calculated, the position estimating unit **55** inputs the moving amount calculated at step S**6** from the moving amount estimating unit **53**, and estimates the current position of the autonomous mobile body **100** based on the input moving amount using the method for estimating the position of the autonomous mobile body **100** according to the above-described map matching (step S**7**).

After the current position of the autonomous mobile body **100** is estimated, the travelling controller **57** calculates driving signals to move the autonomous mobile body **100** from the current position to a next target position, and outputs the driving signal to the motors **23***a* and **23***b* of the travelling unit **2** (step S**8**).

Specifically, the travelling controller **57** inputs the current position of the autonomous mobile body **100** estimated at step S**7** from the position estimating unit **55**. Further, the travelling controller **57** reads the next target position from the storage unit **51** based on the input current position. Thereafter, the travelling controller **57** calculates a control command to move the autonomous mobile body **100** to the read next target position from the current position of the autonomous mobile body **100**.

The control command to be calculated by the travelling controller **57** is calculated as data representing, for example, a relationship between a time during a movement from a current position to a next target position and the speed of the autonomous mobile body **100** (rotational speeds of the wheels **21***a* and **21***b*, namely, rotational speeds of the motors **23***a* and **23***b*).

After the calculation of the control command, the travelling controller **57** calculates driving signal to drive (controlling) the motors **23***a* and **23***b* based on the calculated control command, and outputs the calculated driving signals to the motors **23***a* and **23***b* of the travelling unit **2**.

After the driving signals are output to the travelling unit **2**, the controller **5** determines whether, for example, the autonomous mobile body **100** passes through all the target positions stored in the storage unit **51**, so as to determine whether the autonomous movement is to be ended (step S**9**).

For example, when the determination is made that the autonomous mobile body **100** does not pass through all the target positions and the autonomous movement is to be continued ("No" at step S**9**), the autonomous moving process returns to step S**1** so that the autonomous movement is continued.

On the other hand, when the determination is made that the autonomous mobile body **100** passes through all the target positions and the autonomous movement is to be ended ("Yes" at step S**9**), the autonomous moving process is ended.

In the moving amount estimating unit **53** of the first preferred embodiment, when the first projection object image to be formed by the plurality of first position data matches with the moving projection object image to be formed by the plurality of moving position data, the moving amount of the parallel movement and/or the moving amount of the rotational movement of the second position data in which the moving position data is obtained is determined as the first reference moving amount. In other words, the moving amount, in which the projection object image to be formed by the plurality of second position data is moved so as to match with the first projection object image, is determined as the first reference moving amount. Therefore, an influence of a measurement error included in the plurality of position data is reduced or prevented, so that the first reference moving amount is able to be calculated as a value closer to the actual moving amount of the mobile body.

As a result, the second estimating unit **5312** is able to compensate for the wheel moving amount more accurately using the first reference moving amount calculated by reducing the influence of the measurement error included in the plurality of position data.

In the moving amount estimating unit **53** of the first preferred embodiment, the compensation coefficient calculator **5313** calculates the compensation coefficient based on the first reference moving amount and the second reference moving amount. Further, the second estimating unit **5312** compensates for the wheel moving amount using the compensation coefficient calculated as the result of comparing the first reference moving amount with the second reference moving amount.

As a result, in the moving amount estimating unit **53**, the calculation frequencies of the second reference moving amount and the first reference moving amount are significantly reduced. Further, even when the plurality of position data cannot be obtained while the autonomous mobile body **100** is travelling on a wide area where an obstacle such as a wall is not present therearound, the second estimating unit **5312** is able to compensate for the wheel moving amount more accurately using the compensation coefficient and to calculate the moving amount of the autonomous mobile body **100** more accurately.

Further, the moving amount estimating unit **53** of the autonomous mobile body **100** of this preferred embodiment estimates the moving amount of the autonomous mobile body **100** more accurately. Accordingly, the position estimating unit **55** is able to estimate the position of the autonomous mobile body **100** more accurately. As a result, the travelling controller **57** controls the travelling unit **2** so that the autonomous mobile body **100** is appropriately moved from the current position to a predetermined target position. That is, the autonomous mobile body **100** includes the moving amount estimating unit **53** so that the autonomous mobile body **100** autonomously travels on an intended moving route accurately.

In the method for calculating the compensation coefficient and the method for autonomously moving the autonomous mobile body **100** as illustrated in the flowcharts of FIG. **6** and FIG. **7**, an order of the steps can be arbitrarily changed or the process at each step can be changed within the scope of the present invention.

For example, as an alternative preferred embodiment of the present invention, the compensation coefficient calculator **5313** may calculate a difference between the first reference moving amount and the second reference moving amount as the compensation coefficient. In this case, the second estimating unit **5312** compensates for the wheel moving amount such that the wheel moving amount is not multiplied by the compensation coefficient but the compensation coefficient is added to the wheel moving amount.

Second Preferred Embodiment

The moving amount calculator **531** of the first preferred embodiment preferably does not check whether the compensation coefficient calculated by the compensation coefficient calculator **5313** is appropriately calculated. However, the method is not limited to this. A moving amount calculator **531'** of the second preferred embodiment evaluates whether a compensation coefficient calculated by a compensation coefficient calculator **5313** is appropriate.

For this reason, as illustrated in FIG. **8**, the moving amount calculator **531'** of the second preferred embodiment includes a first estimating unit **5311**, a second estimating unit **5312**, the compensation coefficient calculator **5313**, a compensation data obtaining command unit **5314** (e.g., a compensation data obtaining commander), and an evaluating unit **5315** (e.g., an evaluator). FIG. **8** is a diagram illustrating a configuration of the moving amount calculator according to the second preferred embodiment.

The first estimating unit **5311**, the second estimating unit **5312**, the compensation coefficient calculator **5313**, and the compensation data obtaining command unit **5314** of the moving amount calculator **531'** in the second preferred embodiment preferably have the same configurations and functions as those of the first estimating unit **5311**, the second estimating unit **5312**, the compensation coefficient calculator **5313**, and the compensation data obtaining command unit **5314** in the first preferred embodiment. For this reason, description thereof is omitted. Further, since also a configuration of an autonomous mobile body **100** is the same as that in the first preferred embodiment except for the configuration of the moving amount calculator **531**, description thereof is omitted. For this reason, the following description refers only to the evaluating unit **5315**.

The evaluating unit **5315** evaluates whether the compensation coefficient at this time is appropriately calculated based on a result of comparing the compensation coefficient calculated by the compensation coefficient calculator **5313** at this time with a compensation coefficient that is calculated for a past period in the compensation coefficient calculator **5313** and is stored in a storage unit **51** (referred to as a past compensation coefficient).

When the compensation coefficient is calculated as a ratio between a first reference moving amount and a second reference moving amount and the compensation coefficient calculated at this time is larger than “1”, the evaluating unit **5315** evaluates that the compensation coefficient calculated at this time is calculated inappropriately. The compensation coefficient is evaluated in such a manner for the following reason.

When the compensation coefficient is calculated as a difference between the first reference moving amount and the second reference moving amount, the evaluating unit **5315** evaluates that the compensation coefficient calculated at this time is inappropriate when the compensation coefficient calculated at this time is a positive value (the first reference moving amount is larger than the second reference moving amount).

When the autonomous mobile body **100** is moved on a floor surface by the travelling unit **2** having wheels **21***a* and **21***b*, diameters of the wheels **21***a* and **21***b* typically reduce per travelling. In this preferred embodiment, a state of the compensation coefficient being larger than “1” means a state of the diameters of the wheels **21***a* and **21***b* being larger than diameters of the wheels **21***a* and **21***b* at an unused time. For this reason, the compensation coefficient larger than “1” conflicts with the reduction in the diameters of the wheels **21***a* and **21***b* in response to a travelling distance. When a general phenomenon conflicts with the calculated compensation coefficient in such a manner, the compensation coefficient is evaluated as being calculated inappropriately.

Further, a state of the compensation coefficient calculated at this time becoming larger than the compensation coefficient calculated at a past time conflicts with a state of the diameters of the wheels **21***a* and **21***b* being reduced per travelling (per use) except for a case where the wheels **21***a* and **21***b* are replaced by new ones while the compensation coefficient at a past time is calculated and the compensation coefficient at this time is calculated. Therefore, also when the compensation coefficient calculated at this time becomes larger than the compensation coefficient at the past time, the evaluating unit **5315** evaluate that the compensation coefficient at this time is inappropriately calculated.

A moving amount estimating unit **53** includes the evaluating unit **5315**, so that a determination can be made whether the compensation coefficient calculated at this time is reasonably calculated based on characteristics of the wheels **21***a* and **21***b* in comparison with the past compensation coefficient calculated at a previous time or in consideration for a general phenomenon that happens in the travelling unit **2**.

Further, when the evaluating unit **5315** evaluates that the compensation coefficient is not appropriately calculated, the past compensation coefficient stored in the storage unit **51** is output as the compensation coefficient calculated at this time to the second estimating unit **5312**. That is, when the compensation coefficient at this time is evaluated as not being appropriately calculated, the second estimating unit **5312** uses the past compensation coefficient as the compensation coefficient calculated at this time.

As a result, when the compensation coefficient calculated at this time is calculated as a wrong (unreasonable) value, the second estimating unit **5312** is able to avoid erroneous compensation of the wheel moving amount using the compensation coefficient erroneously calculated.

Third Preferred Embodiment

In the moving amount calculators **531** and **531'** of the first preferred embodiment and the second preferred embodiment, the second estimating unit **5312** calculates the wheel moving amount based on the peripheral lengths calculated based on the reference wheel diameters of the wheels **21***a* and **21***b* and the rotating amounts of the wheels **21***a* and **21***b*, and compensates for the wheel moving amount using the compensation coefficient. However, a subject to be compensated for is not limited to the wheel moving amount.

In a moving amount calculator **531"** of a third preferred embodiment, not a wheel moving amount but wheel diameters of wheels **21***a* and **21***b* are compensated for. The moving amount calculator **531"** of the third preferred embodiment, as illustrated in FIG. **9**, includes a first estimating unit **5311**, a second estimating unit **5312"**, a compensation coefficient calculator **5313**, a compensation data obtaining command unit **5314**, and a diameter change calculator **5316**.

In the third preferred embodiment, the first estimating unit **5311**, the compensation coefficient calculator **5313**, and the compensation data obtaining command unit **5314** preferably have the same configurations and functions as those of the first estimating unit **5311**, the compensation coefficient calculator **5313**, and the compensation data obtaining command unit **5314** of the first preferred embodiment and the second preferred embodiment. For this reason, description of the first estimating unit **5311**, the compensation coefficient calculator **5313**, and the compensation data obtaining command unit **5314** of the third preferred embodiment is omitted.

The second estimating unit **5312"** compensates for the wheel diameters of the wheels **21***a* and **21***b* based on reference wheel diameters and a compensation coefficient. For example, the second estimating unit **5312"** multiplies the reference wheel diameters by the compensation coefficient (when the compensation coefficient is calculated as a ratio between a first reference moving amount and a second reference moving amount) so as to be capable of compensating the wheel diameters of the wheels **21***a* and **21***b*.

On the other hand, when the compensation coefficient is calculated as a difference between the first reference moving amount and the second reference moving amount, the second estimating unit **5312"** adds a change amount of the wheel diameters (wheel diameters to be calculated when the compensation coefficient is set as the wheel moving amount) to the reference wheel diameters so as to be capable of compensating the wheel diameters of the wheels **21***a* and **21***b*.

Further, the second estimating unit **5312"** calculates current peripheral lengths of the wheels **21***a* and **21***b* based on the compensated wheel diameters (referred to as compensation wheel diameters). Further, the second estimating unit **5312"** calculates the wheel moving amount (namely, the moving amount of an autonomous mobile body **100**) based on the current peripheral lengths and the rotating amounts of the wheels **21***a* and **21***b*. As a result, the moving amount of the autonomous mobile body **100** to be calculated based on the rotating amounts of the wheels **21***a* and **21***b* is able to be compensated for and simultaneously the wheel diameters is also able to be compensated for.

The diameter change calculator **5316** calculates a change in the diameters of the wheels **21***a* and **21***b* based on a comparison between the compensation wheel diameters and the reference wheel diameters. For example, a value obtained by subtracting the compensation wheel diameters from the reference wheel diameters as a reduction amount of the diameters of the wheels **21***a* and **21***b*. As to the other portions, the ratio between the reference wheel diameters and the compensation wheel diameters may be calculated as the reduction amount of the diameters of the wheels **21***a* and **21***b*.

When the compensation coefficient is calculated as the difference between the first reference moving amount and the second reference moving amount, wheel diameters to be calculated when the compensation coefficient is used as the wheel moving amount is able to be determined as the change in the diameters of the wheels **21***a* and **21***b*.

The moving amount calculator **531"** includes the diameter change calculator **5316** so that the change in the diameters of the wheels **21***a* and **21***b* is able to be monitored. As a result, for example, when the diameters of the wheels **21***a* and **21***b* are reduced to a predetermined value or less, a user can be notified about a time of replacement of the wheels **21***a* and **21***b* in a manner that an alarm that prompts replacement of the wheels **21***a* and **21***b* is generated or a message to prompt the replacement of the wheels **21***a* and **21***b* is displayed on a display unit (not illustrated) of the operation unit **7**.

Other Preferred Embodiments

The preferred embodiments of the present invention are described above, but the present invention is not limited to the above preferred embodiments, and various modifications can be made within a range that does not deviate from the subject matter of the present invention. In particular, the plurality of preferred embodiments and alternative preferred embodiments described in this specification can be arbitrarily combined as needed.

For example, all the first to third preferred embodiments may be combined. In this case, a moving amount estimating unit **53'"** may include a first estimating unit **5311**, second estimating units **5312** and **5312"**, a compensation coefficient calculator **5313**, a compensation data obtaining command unit **5314**, an evaluating unit **5315**, and a diameter change calculator **5316**. As a result, the moving amount estimating unit **53'"** is able to produce all the effects of the moving amount calculators **531**, **531'**, and **531"** according to the first to third preferred embodiments.

Another Preferred Embodiment of Travelling Unit

The travelling unit **2** according to the first to third preferred embodiments preferably is a two-wheel differential travelling unit. However, not limited to this, use of a travelling unit that has another kind of wheels such as omni wheels can produce the effects of the first to third preferred embodiments.

Another Preferred Embodiment of Moving Amount Calculating Method in First Estimating Unit

In the first estimating unit **5311** of the first to third preferred embodiments, any one of the ICP method and the histogram matching method is preferably used so that the moving amount of the autonomous mobile body **100** is calculated. However, not limited to this, the ICP method and the histogram matching method may be combined so that the moving amount is calculated. For example, a moving amount of the rotational movement of the autonomous mobile body **100** (a change amount of a posture) may be calculated by using the histogram matching method, and a moving amount of the autonomous mobile body **100** (a parallel moving amount) may be calculated by using the ICP method.

The ICP method enables the accurate calculation of the moving amount of the autonomous mobile body **100** but has the following problem. That is, when only the posture of the autonomous mobile body **100** is changed and the posture change amount is calculated by using the ICP method, the moving amount is occasionally calculated in a state that a center point of the posture change shifts before and after the movement. That is, the autonomous mobile body **100** is estimated as being moved parallelly even though it does not moved parallelly. On the other hand, the rotating center hardly moves in the histogram matching method.

Therefore, the posture change amount of the rotational movement of the autonomous mobile body **100** is calculated by using the histogram matching method, and the plurality of second position data is moved by the posture change amount estimated by using the histogram matching method, and the parallel moving amount is calculate by using the second position data and the first position data after the movement according to the ICP method. As a result, the moving amount of the autonomous mobile body **100** is able to be calculated more accurately.

Further, since a calculating amount necessary to calculate the moving amount in the ICP method tends to be larger, the ICP method and the histogram matching method are combined so that a calculating amount necessary to calculate the moving amount in the first estimating unit **5311** is able to be reduced.

Further, when a moving amount is calculated by using a plurality of position data, the plurality of position data is classified into some groups determined base on predetermined conditions, and the moving amount is calculated by using position data included in one group. Thereafter, the plurality of second position data is moved by the moving amount, and a moving amount is further calculated by using position data included in another group. That is, the moving amount may be calculated at multiple-stage. As a result, particularly in the ICP method, the calculating amount necessary to calculate the moving amount is able to be reduced.

Another Preferred Embodiment of Main Body

The main body **1** of the autonomous mobile body **100** according to the first to third preferred embodiments is not particularly mounted with a member that interferes with a position data detectable region of the position data obtaining unit **3**. However, not limited to this, the main body **1** may be mounted with a known-shaped interference member so that at least a portion of the member enters the position data detectable region of the position data obtaining unit **3**.

The main body **1** is mounted with the interference member so that at least a portion of the member enters the position data detectable region, so that a check can be made whether the position data obtaining unit **3** normally operates. For example, when an object such as a wall or an obstacle is not present around the autonomous mobile body **100** and a projection object image corresponding to the shape of the portion of the interference member is formed by some of the plurality of position data, the determination can be made not that position data are not obtained due to a malfunction of the position data obtaining unit **3** but that the autonomous mobile body **100** is moving in a wide space where no object is present.

Another Preferred Embodiment of Use of Compensation Coefficient

In the first to third preferred embodiments, the compensation coefficient calculated by the compensation coefficient calculator **5313** is used to compensate for wheel moving amounts or diameters of wheels **21***a* and **21***b*. However, not limited to this, the compensation coefficient may be used to check a state of the floor surface in the moving region.

For example, in a preferred embodiment where the compensation coefficient calculator **5313** calculates the compensation coefficient as a ratio between a first reference moving amount and a second reference moving amount, when the calculated compensation coefficient is a small value, a determination is able to be made that the floor surface in the moving region is wet or a lot of objects such as sand that make the autonomous mobile body **100** skid are present on the floor surface. This is because when the floor surface is wet or is slippery due to sand the actual moving amount of the autonomous mobile body **100** is small even if the wheels **21***a* and **21***b* rotate a lot.

For example, when the autonomous mobile body **100** according to the first to third preferred embodiments is applied to a cleaning robot, a location to be cleaned is able to be determined based on the compensation coefficient. For example, the cleaning robot is able to be instructed to intensively clean a location where the calculated compensation coefficient is a small value. In a preferred embodiment where the compensation coefficient calculator **5313** calculates the compensation coefficient as the difference between the first reference moving amount and the second reference moving amount, a case where an absolute value of the compensation coefficient is calculated as a large value is detected so that the same effect as the above one is able to be produced.

In another manner, the compensation coefficient calculated by the compensation coefficient calculator **5313** and the change amount of the wheel diameters calculated by the diameter change calculator **5316** are saved in a storage medium inside and/or outside the autonomous mobile body **100**, and the saved compensation coefficient and change amount of the wheel diameters may be read to be used when the autonomous mobile body **100** is activated next time. As a result, the predetermined period for again calculating the compensation coefficient and the diameter change amount is not necessary, and thus the moving amount and the wheel diameters is able to be compensated for instantly.

In the second preferred embodiment, the compensation coefficient calculated by the compensation coefficient calculator **5313** is evaluated only by the evaluating unit **5315**, but the compensation coefficient may be reevaluated based on a result of map matching in the SLAM method. For example, the wheel moving amount compensated for by the second estimating unit **5312** is compared with an estimated moving amount of the map matching (corresponding to a difference between a self position of the autonomous mobile body **100** before a movement and a self position of the autonomous mobile body **100** after the movement estimated by the map matching). When an absolute error between the wheel moving amount before the compensation and the estimated moving amount of the map matching is small and an absolute error between the compensated wheel moving amount and the estimated moving amount of the map matching is large, the compensation coefficient calculated by the compensation coefficient calculator **5313** may be determined as being inappropriate.

Further, the compensation coefficient and/or the diameter change may be recalculated based on the comparison between the wheel moving amount and the estimated moving amount of the map matching. As a result, the evaluation is able to be further made whether the compensation coefficient calculated by the compensation coefficient calculator **5313** is appropriate. Alternatively, the compensation coefficient is able to be evaluated also by using the estimated moving amount of the map matching (namely, the wheel moving amount can be compensated for) as needed.

In another manner, as modes of the map matching based on the second reference moving amount (the wheel moving amount) and the map matching based on the moving amounts compensated for by the second estimating units **5312** and **5312"**, a matching degree of the map matching based on the wheel moving amount (a maximum value of a posterior probability or the like) is compared with a matching degree of the map matching based on the moving amounts compensated for by the second estimating units **5312** and **5312"** (maximum value of the posterior probability). When the matching degree of the map matching based on the moving amount compensated for by the second estimating units **5312** and **5312"** is small, the compensation coefficient calculated by the compensation coefficient calculator **5313** may be determined as inappropriate.

As a result, an evaluation is able to be further made whether the compensation coefficient calculated by the compensation coefficient calculator **5313** is appropriate. The posterior probability is an index representing a level of the matching result, and as the result of map matching is better, namely, the position is estimated more accurately, the value becomes larger.

In the above preferred embodiments, a moving amount of the autonomous mobile body **100** on a two-dimensional plane is estimated by using LRF that obtains two-dimensional position data as the position data obtaining unit, but a moving amount of the autonomous mobile body **100** in a three-dimensional space is also able to be estimated by using a ToF camera or the like that is able to obtain a three-dimensional position data.

Various preferred embodiments of the present invention is able to be widely applied to any mobile body that is able to be moved by rotation of a wheel.

While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A moving amount estimating apparatus for estimating a moving amount of a mobile body moving according to rotation of a wheel, the apparatus comprising:

a position data detector that obtains a plurality of position data to form a projection object image obtained by projecting an object around the mobile body onto a predetermined coordinate; and

a processor configured or programmed to include:

a first estimator that calculates, when a first projection object image formed by a plurality of first position data obtained one of before and after the mobile body moves matches with a moving projection object image formed by a plurality of moving position data obtained by a parallel movement and/or a rotational movement of a plurality of second position data obtained the other of before and after the movement on the predetermined coordinate, a moving amount of the parallel movement and/or a moving amount of the rotational movement of the plurality of second position data as a moving amount in which the mobile body moves;

a second estimator that compensates for a wheel moving amount to be calculated based on a rotating amount of the wheel based on a comparison between a second reference moving amount calculated based on the rotating amount of the wheel for a predetermined period during which the mobile body is moving and a first reference moving amount that is a calculated value of the moving amount in the first estimator when the mobile body moves during the predetermined period so as to estimate the compensated wheel moving amount as the moving amount of the mobile body; and

a compensation coefficient calculator that calculates a compensation coefficient as a result of comparing the second reference moving amount with the first reference moving amount based on the first reference moving amount and the second reference moving amount; wherein

the second estimator compensates for the wheel moving amount using the compensation coefficient, and calculates a compensation wheel diameter based on a reference wheel diameter as a predetermined diameter of the wheel and the compensation coefficient so as to calculate the moving amount of the mobile body based on the compensation wheel diameter and the rotating amount of the wheel.

2. The moving amount estimating apparatus according to claim **1**, wherein the processor is further configured or programmed to include an evaluator that evaluates whether the compensation coefficient is calculated appropriately based on a result of comparing a past compensation coefficient calculated during a past period before the predetermined period with the compensation coefficient.

3. The moving amount estimating apparatus according to claim **2**, wherein when a determination is made that the compensation coefficient is not appropriately calculated, the second estimator uses the past compensation coefficient as the compensation coefficient.

4. The moving amount estimating apparatus according to claim **1**, wherein the compensation coefficient calculator calculates the compensation coefficient based on the first reference moving amount, the second reference moving amount, and an updated coefficient having a predetermined value.

5. The moving amount estimating apparatus according to claim **1**, wherein the second estimator calculates the wheel moving amount based on a reference wheel diameter as a predetermined diameter of the wheel and the rotating amount of the wheel so as to compensate for the wheel moving amount based on the compensation coefficient.

6. The moving amount estimating apparatus according to claim **1**, wherein the processor is further configured or programmed to include a diameter change calculator that calculates a change in the diameter of the wheel based on a comparison between the compensation wheel diameter and the reference wheel diameter.

7. The moving amount estimating apparatus according to claim **1**, wherein the processor is further configured or programmed to include a compensation data obtaining commander that specifies the predetermined period in which the first reference moving amount and the second reference moving amount are calculated.

8. An autonomous mobile body comprising:

a travelling unit that includes a wheel and is capable of travelling according to rotation of the wheel;

a position data detector that obtains a plurality of position data to form a projection object image obtained by projecting an object around the mobile body onto a predetermined coordinate; and

a processor configured or programmed to include:

a first estimator that calculates, when a first projection object image formed by a plurality of first position data obtained one of before and after the mobile body moves matches with a moving projection object image formed by a plurality of moving position data obtained by a parallel movement and/or a rotational movement of a plurality of second position data obtained the other of before and after the movement on the predetermined coordinate, a moving amount of the parallel movement and/or a moving amount of the rotational movement of the plurality of second position data as a moving amount in which the mobile body moves;

a second estimator that compensates for a wheel moving amount to be calculated based on a rotating amount of the wheel based on a comparison between a second reference moving amount calculated based on the rotating amount of the wheel for a predetermined period during which the mobile body is moving and a first reference moving amount that is a calculated value of the moving amount in the first estimator when the mobile body moves during the predetermined period so as to estimate the compensated wheel moving amount as the moving amount of the mobile body;

a compensation coefficient calculator that calculates a compensation coefficient as a result of comparing the second reference moving amount with the first reference moving amount based on the first reference moving amount and the second reference moving amount;

a position estimator that estimates a current position based on a moving amount to be estimated in a moving amount estimating apparatus; and

a travelling controller that controls the travelling unit so that the travelling unit travels from the current position to a predetermined target position; wherein

the second estimator compensates for the wheel moving amount using the compensation coefficient, and calculates a compensation wheel diameter based on a reference wheel diameter as a predetermined diameter of the wheel and the compensation coefficient so as to calculate the moving amount of the mobile body based on the compensation wheel diameter and the rotating amount of the wheel.

9. A moving amount estimating method for estimating a moving amount of a mobile body moving according to rotation of a wheel, the method comprising:

obtaining a plurality of position data to form a projection object image obtained by projecting an object present around the mobile body onto a predetermined coordinate before and after the mobile body moves during a predetermined period;

moving a plurality of second position data obtained one of before and after the movement parallelly and/or rotationally on the predetermined coordinate so as to calculate a plurality of moving position data;

calculating, when the plurality of moving position data is obtained such that a first projection object image to be formed by a plurality of first position data obtained the other of before and after the movement matches with a moving projection object image to be formed by the plurality of moving position data, a first reference moving amount based on a moving amount of the parallel movement and/or a moving amount of the rotational movement of the plurality of second position data;

calculating a second reference moving amount based on the rotating amount of the wheel during the predetermined period;

compensating a wheel moving amount to be calculated based on the rotating amount of the wheel based on a comparison between the second reference moving amount and the first reference moving amount;

estimating the compensated wheel moving amount as the moving amount of the mobile body;

calculating a compensation coefficient as a result of comparing the second reference moving amount with the first reference moving amount based on the first reference moving amount and the second reference moving amount;

compensating for the wheel moving amount using the compensation coefficient;

calculating a compensation wheel diameter based on a reference wheel diameter as a predetermined diameter of the wheel and the compensation coefficient; and

calculating the moving amount of the mobile body based on the compensation wheel diameter and the rotating amount of the wheel.

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