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POSITION ESTIMATION DEVICE, POSITION ESTIMATION METHOD, AND STORAGE MEDIUM STORING POSITION ESTIMATION PROGRAM

Abstract

A position estimation device that estimates a position of a mobile object provided with a distance measurement sensor, includes processing circuitry to extract feature points from distance measurement data outputted from the distance measurement sensor to estimate restriction information indicating a direction in which posture assumed by a feature value of each of the feature points is restricted; to determine weights, to be respectively assigned to the feature points, based on the restriction information; and to calculate a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying evaluation values representing differences by the weights is minimized, the differences being differences between the feature points of the distance measurement data and corresponding points respectively corresponding to the feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a continuation application of International Application No. PCT/JP2022/045766 having an international filing date of Dec. 13, 2022.

BACKGROUND OF THE INVENTION
1. Field of the Invention
[0002] The present disclosure relates to a position estimation device, a position estimation method and a position estimation program.
2. Description of the Related Art
[0003] There has been proposed a positioning system including a reference data DB storing reference data, a feature point extraction unit that extracts feature points from a captured image that has captured scenery viewed from a vehicle, a captured image processing unit that generates feature point data in regard to each captured image from the feature points and outputs the feature point data as matching data for matching, and a scenery matching unit that performs the matching between reference data extracted from the reference data DB and the matching data and determines the position of the host vehicle based on a photographing position associated with reference data that succeeded in the matched (see Patent Reference 1, for example). In this positioning system, at the time of constructing the reference data DB, weights are assigned to the feature points based on distribution of the feature points or the like.
[0004] Patent Reference 1: Japanese Patent Application Publication No. 2011-215972 (see paragraphs **0016** to **0019**, for example). However, in the conventional positioning system described above, at the time of the position estimation based on sensor data from a distance measurement sensor (e.g., LiDAR, camera or the like), the position is estimated without considering the most recent posture of the distance measurement sensor. Therefore, the conventional positioning system is incapable of obtaining position information with high accuracy.
SUMMARY OF THE INVENTION
[0005] An object of the present disclosure, which has been made to resolve problems like that described above, is to provide a position estimation device, a position estimation method and a position estimation program that make it possible to increase the accuracy of the position estimation.
[0006] A position estimation device in the present disclosure is a device that estimates a position of a mobile object provided with a distance measurement sensor that detects a surrounding environment. The position estimation device includes processing circuitry to extract a plurality of feature points from distance measurement data outputted from the distance measurement sensor to estimate restriction information indicating a direction in which posture assumed by a feature value of each of the plurality of feature points is restricted by using a SHOT method, when calculating the posture of the distance measurement sensor based on the plurality of feature points; to determine a plurality of weights, to be respectively assigned to the plurality of feature points, based on the restriction information indicating a restriction direction in which the posture is restricted;

and to calculate a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying a plurality of evaluation values representing differences by the plurality of weights is minimized, the differences being differences between the plurality of feature points of the distance measurement data and a plurality of corresponding points respectively corresponding to the plurality of feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object by using the rotation amount and the translation amount.

[0007] A position estimation method in the present disclosure is a method to be executed by a position estimation device that estimates a position of a mobile object provided with a distance measurement sensor that detects a surrounding environment. The method includes extracting a plurality of feature points from distance measurement data outputted from the distance measurement sensor; estimating restriction information indicating a direction in which posture assumed by a feature value of each of the plurality of feature points is restricted by using a SHOT method, when calculating the posture of the distance measurement sensor based on the plurality of feature points; determining a plurality of weights, to be respectively assigned to the plurality of feature points, based on the restriction information indicating a restriction direction in which the posture is restricted; and calculating a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying a plurality of evaluation values representing differences by the plurality of weights is minimized, the differences being differences between the plurality of feature points of the distance measurement data and a plurality of corresponding points respectively corresponding to the plurality of feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object by using the rotation amount and the translation amount.

Effect of the Invention

[0008] According to the present disclosure, the accuracy of the position estimation can be increased.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

[0010] FIG. **1** is a diagram showing an example in which a position estimation device according to a first embodiment is mounted on a vehicle as a mobile object;

[0011] FIG. **2** is a block diagram schematically showing the configuration of the position estimation device according to the first embodiment;

[0012] FIG. **3** is a diagram showing an example of the hardware configuration of the position estimation device according to the first embodiment;

[0013] FIG. **4** is a diagram showing an example of a plurality of feature points obtained by a feature extraction unit in FIG. **2**;

[0014] FIGS. **5**A and **5**B are schematic diagrams showing an estimated axial direction of a posture at each feature point;

[0015] FIGS. **6**A and **6**B are schematic diagrams showing a histogram in regard to normal vectors of feature points in each region and frequency information in regard to each restriction that each feature point in the respective region has;

[0016] FIG. **7** is a flowchart showing the operation of the position estimation device according to the first embodiment; and

[0017] FIG. **8** is a diagram showing an example in which a position estimation device according to

a second embodiment is mounted on a three-dimensional measurement device as the mobile object.
DETAILED DESCRIPTION OF THE INVENTION

[0018] A position estimation device, a position estimation method and a position estimation program according to each embodiment will be described below with reference to the drawings. The following embodiments are just examples and it is possible to appropriately combine embodiments and appropriately modify each embodiment.

<1> First Embodiment

<1-1> Configuration

(General Outline of Position Estimation Device **11**)

[0019] FIG. **1** is a diagram showing an example in which a position estimation device **11** according to a first embodiment is mounted on a vehicle as a mobile object **10**. As shown in FIG. **1**, the mobile object **10** includes a position estimation system that estimates its own position. The position estimation system includes a distance measurement sensor **12** that measures a surrounding environment, a condition sensor **13** that acquires a steering angle, speed, acceleration and so forth of the mobile object, a GNSS receiver **15** as a position information receiver that acquires an absolute position of the mobile object **10** from a GNSS (Global Navigation Satellite System), and the position estimation device **11** that executes processing such as the position estimation based on sensor data acquired from the distance measurement sensor **12**, the condition sensor **13** and the GNSS receiver **15**. The distance measurement sensor **12** includes one or more out of a LiDAR (Light Detection and Ranging) **121**, a camera **122** and a millimeter-wave radar **123**. The condition sensor **13** may include an inertial sensor that obtains inertial information regarding the mobile object. The mobile object **10** can be an autonomous driving vehicle, a PMV (Personal Mobility Vehicle), an AMR (Autonomous Mobile Robot), a drone as an unmanned aircraft, or the like, for example.

[0020] FIG. **2** is a block diagram schematically showing the configuration of the position estimation device **11** according to the first embodiment. The position estimation device **11** is a device that executes a position estimation method according to the first embodiment, such as a computer that executes a position estimation program according to the first embodiment, for example. As shown in FIG. **2**, the position estimation device **11** includes a distance measurement data acquisition unit **100** that acquires distance measurement data as the sensor data from the distance measurement sensor **12**, a feature extraction unit **101** that extracts feature points (and their feature values) from the distance measurement data, a posture information calculation unit **102** that calculates posture information regarding posture (i.e., posture of the distance measurement sensor **12**, that is, posture of the mobile object **10**) based on distribution of the extracted feature points, a feature value weight determination unit **103**, a position estimation unit **107**, a local map generation unit **108**, a map generation unit **109**, and a map database (map DB) **110**. Further, the position estimation device **11** includes a posture accumulation unit **104** that acquires condition information from the condition sensor **13**, a coordinate axis transformation unit **105** that acquires position information (absolute position information) from the GNSS receiver **15**, and a preliminary posture integration unit **106**. The map database **110** may also be provided in an external storage device.

[0021] The position estimation device **11** estimates the position of the mobile object **10** including at least the distance measurement sensor **12** that detects the surrounding environment. The position estimation device **11** includes the feature extraction unit **101** that extracts a plurality of feature points from the distance measurement data outputted from the distance measurement sensor **12**, the posture information calculation unit **102** that calculates the posture information indicating the posture of the distance measurement sensor **12** (i.e., the posture of the mobile object **10**) based on the plurality of feature points F, the feature value weight determination unit **103** that determines a plurality of weights W.sub.feature, to be respectively assigned to the plurality of feature points F, based on the distribution of the plurality of feature points F, and the position estimation unit **107** that estimates the position of the mobile object **10** based on the plurality of feature points F of the distance measurement data, a plurality of corresponding points in the stored map information respectively corresponding to the plurality of feature points F, the calculated posture information, and the plurality of weights W.sub.feature. The posture information, the plurality of feature points F and the plurality of weights W.sub.feature will be described later.

[0022] Further, the position estimation unit **107** estimates the position of the mobile object **10**, including the distance measurement sensor **12** that detects position posture information indicating the position and posture of the distance measurement sensor **12**, based on condition data outputted from the condition sensor **13** included in the mobile object **10** and position data outputted from the GNSS receiver **15** included in the mobile object **10**. The position estimation unit **107** uses the position posture information, obtained by integrating the condition data outputted from the condition sensor **13** included in the mobile object **10** and the position data outputted from the GNSS receiver **15** included in the mobile object **10**, as an initial value in matching between the plurality of feature points F and the plurality of corresponding points.

[0023] FIG. **3** is a diagram showing an example of the hardware configuration of the position estimation device **11** according to the first embodiment. The position estimation device **11** includes, for example, a processor **31** such as a CPU (Central Processing Unit), a memory **32**, a nonvolatile storage device **33**, and an input-output (I/O) interface **34**. Parts constituting the position estimation device **11** are formed with processing circuitry, for example. The processing circuitry can either be dedicated hardware or include a CPU that executes a program (e.g., position estimation program) stored in the memory **32**. The processor **31** implements functional blocks shown in FIG. **2**.

[0024] The memory **32** is a semiconductor memory such as a RAM (Random Access Memory), for example, and the storage device **33** is an HDD (Hard Disk Drive), an SSD (Solid State Drive) or the like. The position estimation device **11** can also be a mixture of components made with processing circuitry and components made with a processor. Further, part or the whole of the position estimation device **11** can be a server computer on a network. Incidentally, the position estimation program is provided by means of downloading via a network, or through a storage medium (i.e., a recording medium) storing information such as a USB memory. The storage record medium is a non-transitory computer-readable storage medium (as a non-transitory tangible medium) storing a program such as the position estimation program. The hardware configuration in FIG. **3** is just an illustration and thus modification is possible.

[0025] When estimating the position of the mobile object **10**, the processing circuitry including the processor **31** of the position estimation device **11** extracts a plurality of feature points from distance measurement data outputted from the distance measurement sensor **12**; estimates restriction information indicating a direction in which posture assumed by a feature value of each of the plurality of feature points is restricted by using a SHOT method, when calculating the posture of the distance measurement sensor **12** based on the plurality of feature points; determines a plurality of weights, to be respectively assigned to the plurality of feature points, based on the restriction information indicating a restriction direction in which the posture is restricted; and calculates a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying a plurality of evaluation values representing differences by the plurality of weights is minimized, the differences being differences between the plurality of feature points of the distance measurement data and a plurality of corresponding points respectively corresponding to the plurality of feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object **10** by using the rotation amount and the translation amount.

(Condition Sensor **13**)

[0026] The condition sensor **13** includes an IMU (Inertial Measurement Unit) mounted on the mobile object **10**, a sensor that measures a kinetic condition of the mobile object **10**, or the like. The condition data as the sensor data obtained by the condition sensor **13** is sent to the memory **32** via the input-output interface **34** and temporarily stored in the memory **32**. The condition data stored in the memory **32** is called up by the posture accumulation unit **104** and is used for the calculation of the posture of the mobile object **10**. Concrete examples of the sensor that measures the kinetic condition are sensors that detect input information to the mobile object **10**, such as a speed sensor like a speedometer and a rotary encoder that detects the steering angle; however, the sensor may include other types of sensors. Kinetic condition data stored in the memory **32** is called up by the posture accumulation unit **104** and is used for the calculation of the posture of the mobile object **10**.

(Distance Measurement Sensor **12**)

[0027] The distance measurement sensor **12**, such as a LiDAR (Light Detection and Ranging) mounted on the mobile object **10**, a camera as an image capturing device, a millimeter-wave radar, or a sonar (Sound Navigation and Ranging), acquires surrounding environment information by detecting the environment surrounding the mobile object **10**. The distance measurement data obtained by the distance measurement sensor **12** is sent to the memory **32** via the input-output interface **34** and temporarily stored in the memory **32**. The distance measurement data stored in the memory **32** is called up by the feature extraction unit **101** and is used for the calculation of the posture information on the mobile object **10**.

(Distance Measurement Data Acquisition Unit **100**)

[0028] The distance measurement data acquisition unit **100** receives the distance measurement data as the sensor data transmitted from the distance measurement sensor **12** and converts the distance measurement data to data in a prescribed data format. While a generic communication standard such as serial communication or Ethernet can be used for the communication of the distance measurement data, it is also possible to use an original communication standard. The distance measurement data received by the distance measurement data acquisition unit **100** is temporarily stored in a buffer, thereafter converted to the prescribed data format, and outputted to the feature extraction unit **101**.

(Feature Extraction Unit **101**)

[0029] The feature extraction unit **101** extracts various types of feature values from the distance measurement data inputted from the distance measurement data acquisition unit **100**. In the case where the distance measurement sensor **12** is a LiDAR, three-dimensional features (edges, corners and planes) obtained from point cloud data including a plurality of feature points are used; however, it is also possible to use other feature values. The feature extraction unit **101** outputs the extracted various types of feature values to the posture information calculation unit **102**.

[0030] FIG. **4** is a diagram showing an example of the plurality of feature points F (a plurality of black circles in a photographing range **72**) obtained by the feature extraction unit **101** in FIG. **2**. This example shows an environment in which there is a bias in the distribution of the feature points F in each region as viewed from the mobile object **10** traveling ahead towards an intersection where there are things such as a traffic light **71**. In such cases where the surrounding environment of the mobile object **10** includes a plurality of unevenly distributed feature points, or in an environment in which a feature is monotonous (e.g., floor surface or wall surface of a corridor in a monotonous shape, ground surface in an open site, or the like), the position estimation device **11** is likely to cause a situation of falling into a local solution at the time of the position estimation. Therefore, the position estimation device **11** in the first embodiment includes the position estimation unit **107** that estimates the position of the mobile object **10** based on the plurality of feature points F of the distance measurement data, the plurality of corresponding points in the stored map information respectively corresponding to the plurality of feature points F, the calculated posture information, and the plurality of weights W.sub.feature.

(Posture Information Calculation Unit **102**)

[0031] The posture information calculation unit **102** calculates the weight (i.e., weight coefficient) of each feature point based on restriction information indicating a direction in which posture assumed by the feature value of each feature point F extracted by the feature extraction unit **101** is restricted. As a concrete example, when a plane is used as a feature point, the feature value is represented by a normal vector to each point. An evaluation function in the matching when using a plane as a feature point is in many cases represented by the plane and the length of a perpendicular line meeting the plane.

[0032] FIGS. **5**A and **5**B are schematic diagrams showing an estimated axial direction of the posture at each feature point. As shown in FIG. **5**A, when a plane is used as a feature point in the estimation of the posture, the posture information estimated by using each feature point includes a movement amount (distance D**1**) in a normal direction (the direction of a normal line **41***a* and the direction of a normal line **42***a*) with respect to planes (plane **41** and plane **42**) and rotation amounts of rotation (arrow **46**) around the normal line **41***a* and rotations around rotation axes in two axial directions (the direction of an axis **43** and the direction of an axis **44**) orthogonal to the normal direction.

[0033] Similarly, as shown in FIG. **5**B, when a feature point at an edge is used as a feature point in the estimation of the posture, the evaluation function in the matching is considered by using a perpendicular line (normal line **53**) extending from an edge (e.g., edge **51**) to meet another edge (e.g., edge **52**). In that case, the movement amount in a plane orthogonal to an edge (e.g., the edge **51**) and rotations (rotations in directions of arrows **56***a*, **56***b* and **56***c*) around rotation axes in the edge direction (the direction of an axis **51***a*) and two axial directions (the direction of an axis **51***b* and the direction of an axis **51***c*) orthogonal to the edge direction can be obtained by calculation.

[0034] Therefore, when estimating the posture information on the mobile object **10** in the present frame from data in the previous frame based on the feature points shown in FIGS. **5**A and **5**B, the posture information calculation unit **102** is capable of estimating in which axial direction the restriction is (i.e., which axial direction is a restriction direction). The posture information calculation unit **102** performs the weighting by considering the distribution of the feature points having such restrictions.

[0035] FIGS. **6**A and **6**B are schematic diagrams showing an example of a histogram in regard to normal vectors of feature points in each region and frequency information in regard to each restriction that each feature point has. The processing regarding the distribution of the feature points may be executed by using a method like SHOT (Signatures of Histograms of Orientations), for example. The SHOT is one type of a point cloud feature value that uses a histogram of the inner product between a neighborhood point set and a normal vector regarding a central point **60**, included in each of eight regions obtained by splitting a sphere **61** defined around the central point **60** as a representative point (splitting at an xy plane, a yz plane and an xz plane into eight regions), as the feature, and the frequency information in regard to each restriction that each feature point has can be obtained by generating the eight regions obtained by bisecting the sphere **61** respectively around the xyz-axes in a certain local coordinate system and generating the histogram of the normal vectors of the feature points in each region as shown in FIGS. **6**A and **6**B according to this method. Here, in FIG. **6**B, the vertical axis represents the histogram and the horizontal axis represents the feature value (the direction restricted by the feature point).

[0036] Further, as a method other than the method using a histogram like the SHOT, it is possible, for example, to generate a three-dimensional normal distribution based on feature points based on normal vectors of plane features and use the frequency of each feature point. The obtained histogram is outputted to the feature value weight determination unit **103**.

(Feature Value Weight Determination Unit **103**)

[0037] The feature value weight determination unit **103** performs the weighting in regard to each feature point based on the histogram calculated by the posture information calculation unit **102**. As a method of calculating the weight W.sub.feature based on the histogram, it is possible, for example, to set the weight based on the frequency in the histogram as shown in the following expression (1):

[00001] $w_{\text{feature}} = \frac{1}{1+f}$. (1)

[0038] In the expression (1), W.sub.feature represents the weight and f represents the frequency in the histogram. The frequency f is represented by a value, that is, a ratio, in a range from 0 to 1. The feature value weight determination unit **103** outputs the weight W.sub.feature in regard to each feature point calculated according to the expression (1) to the position estimation unit **107**.

(Posture Accumulation Unit **104**)

[0039] The posture accumulation unit **104** calculates the posture information (e.g., speed, angular speed and roll-pitch-yaw) in the latest data frame by using the condition data as the sensor data received from the condition sensor **13**. As the condition sensor **13**, an inertial sensor such as an acceleration sensor or a gyro sensor can be used. In the case of using an inertial sensor, sensor data such as acceleration or angular speed is generally outputted as the condition data. Even though such a value does not directly represent the movement amount of the device, the latest posture information can be obtained by successively updating the posture information by integrating the condition data from the measurement start time. The posture accumulation unit **104** outputs the obtained posture information to the preliminary posture integration unit **106**.

(Coordinate Axis Transformation Unit **105**)

[0040] The coordinate axis transformation unit **105** transforms latitude longitude information measured by the GNSS receiver **15** into a coordinate system to be used by the mobile object **10** for the own position estimation. For such coordinate systems, reference points as references have generally been set at various places around the world and a plane rectangular coordinate system having such a reference point as the origin is used in many cases. In Japan, for example, 19 reference points have been prepared and coordinate values in an xy coordinate system around each point as the reference are calculated by a predetermined calculation method (described in Non-patent Reference 1). The coordinate axis transformation unit **105** outputs the calculated position information to the preliminary posture integration unit **106**.

[0041] Non-patent Reference 1: Kazushige Kawazu, “A More Concise Method of Calculation for the Coordinate Conversion between Geographic and Plane Rectangular Coordinates on the Gauss-Kruger Projection”, Journal of the Geospatial Information Authority of Japan, 2011, No. 121, pp. 109-124, URL: https://www.gsi.go.jp/common/000061216.pdf

(Preliminary Posture Integration Unit **106**)

[0042] The preliminary posture integration unit **106** calculates integrated position posture information based on the estimated posture information obtained by the posture accumulation unit **104** based on the condition data and the position information obtained by the coordinate axis transformation unit **105**. While a Kalman filter or the like is generally used as the method of integrating multiple items of sensor information, it is also possible to employ a different method such as obtaining a weighted average based on variance values of the items of the estimated posture information or determining a representative value by means of a voting system.

(Position Estimation Unit **107**)

[0043] The position estimation unit **107** calls up the feature values extracted from the distance measurement data by the feature extraction unit **101** and local map information generated by the local map generation unit **108** which will be described later, searches for corresponding points between the map and newly measured distance measurement data, and estimates a posture that minimizes (or maximizes) a cost function representing the difference between these two point clouds.

[0044] As typical posture estimation methods, there are LOAM (Lidar Odometry and Mapping) as a method using a 3D LiDAR as the distance measurement sensor and Cartographer as a method using a 2D LiDAR as the distance measurement sensor. In these methods, the movement amount can be calculated generally by forming pairs of similar points between the latest distance measurement data and distance measurement data obtained in the immediately previous measurement or points that have been measured so far and obtaining rotation-translation that minimizes distances between the similar points in the pairs. Relationship between the similar points (feature points) can be represented as in the following expression (2):

[00002] $y = Rx + t$. (2)

[0045] In the expression (2), y represents the position of the feature point in the immediately previous distance measurement data, R represents a rotation matrix, x represents the position of the feature point in the latest distance measurement data, and t represents a translation vector.

[0046] This is equivalent to obtaining change amounts of the posture between two pieces of distance measurement data by obtaining a translation amount and a rotation amount that make the same points coincide with each other between the two pieces of distance measurement data. In reality, however, it is difficult to uniquely obtain the solutions since the number of equations becomes greater relative to the number of parameters desired to be obtained due to influence of noise or the like. Therefore, an evaluation function represented by the following expression (3) is used and solutions minimizing an evaluation value obtained by this evaluation function are obtained approximately:

[00003] $\min \sum_{i=0}^{n} \| y_i - (Rx_i + t) \|^2$. (3)

[0047] As a method for solving such a problem, it is generally possible to transform the expression into a computable form by using singular value decomposition (SVD) or the like and then obtain optimum solutions by an optimization method such as the Newton's method or the Levenberg-Marquardt algorithm. However, with the evaluation function in the expression (3), when feature points are concentrated on a particular surface or a particular edge, there is a possibility that the evaluation value obtained by the expression (3) becomes less than or equal to a threshold value even supposing that the rotation amount and the translation amount in a direction other the axial direction estimated by using those feature points have not converged.

[0048] Therefore, erroneous convergence of the calculation (i.e., the evaluation value erroneously becoming less than or equal to the threshold value) due to part of the feature points can be inhibited by using an expression obtained by adding weights w.sub.i previously calculated respectively for the feature points as square error coefficients to the expression (3), such as the following expression (4):

[00004] $\min \sum_{i=0}^{n} w_i \| y_i - (Rx_i + t) \|^2$. (4)

(Local Map Generation Unit **108**)

[0049] When the position estimation unit **107** has already executed the position estimation and map information generated so far exists in the map DB **110**, the local map generation unit **108** generates local map data regarding the vicinity of the own position of the mobile object **10** from these pieces of map information.

(Map Generation Unit **109**)

[0050] The map generation unit **109** performs coordinate transformation on the distance measurement data acquired by the distance measurement data acquisition unit **100** based on the posture information obtained when the calculation result (evaluation value) fell below the threshold value or a predetermined number of trials was exceeded in the position estimation unit **107**. Then, the map generation unit **109** extends the map information by adding the distance measurement data after undergoing the coordinate transformation to the map DB **110**.

[0051] The position estimation device **11** estimates the own position of the mobile object **10** by using the data acquired from the distance measurement sensor **12**, the condition sensor **13** and the GNSS receiver **15** via the input-output interface **34**. The position estimation device **11** estimates the change amounts of the posture (= (movement amount)+ (change amounts of roll-pitch-yaw)) by making the association between data frames by using the feature values extracted from the acquired distance measurement data, and estimates the own position with high accuracy by integrating the posture information acquired from the condition sensor **13** and the GNSS receiver **15**.

<1-2> Operation

[0052] FIG. **7** is a flowchart showing the operation of the position estimation device **11** according to the first embodiment.

(Step S**10**)

[0053] In step S**10**, the posture accumulation unit **104** calculates odometry based on the condition data as the sensor data acquired from the condition sensor **13** (e.g., information such as the acceleration, the angular speed or the steering angle). In parallel with this processing, the coordinate axis transformation unit **105** performs the coordinate transformation on the position information obtained by the GNSS receiver **15** and makes the coordinates after the transformation coincide with the coordinates of the position information calculated by the posture accumulation unit **104**.

(Step S**11**)

[0054] In step S**11**, the preliminary posture integration unit **106** integrates the information obtained by the condition sensor **13** and calculated by the posture accumulation unit **104** in the step S**10** with the position information obtained by the GNSS receiver **15** and underwent the coordinate transformation in the step S**10**. As the method of the integration, a method using a Kalman filter or the like can be used, and the preliminary posture integration unit **106** outputs the result of the estimation to the position estimation unit **107** as a preliminarily estimated own position.

(Step S**12**)

[0055] In step S**12**, the distance measurement data acquisition unit **100** receives the distance measurement data as the sensor data from the distance measurement sensor **12** and converts the received distance measurement data to distance measurement data as data in a predetermined format.

(Step S**13**)

[0056] In step S**13**, the feature extraction unit **101** calculates the feature values to be used for the data matching between frames from the distance measurement data converted into the predetermined format in the step S**12**. For example, the feature extraction unit **101** calculates information such as a change amount of luminance and three-dimensional shapes (plane, edge, etc.) of the surrounding environment from the distance measurement data.

(Step S**14**)

[0057] In step S**14**, the posture information calculation unit **102** calculates which posture each of the feature values detected by the feature extraction unit **101** has restriction on. Further, the feature value weight determination unit **103** sets the weight of each feature value to be used in the posture estimation as a subsequent process at a value in a range from 0 to 1 based on the information calculated by the posture information calculation unit **102**.

(Step S**15**)

[0058] In step S**15**, for the posture estimation to be executed by using the feature values calculated in the step S**13**, the position estimation unit **107** employs the posture information estimated by the preliminary posture integration unit **106** as the initial value of the matching.

(Step S**16**)

[0059] In step S**16**, when the position estimation has been executed in the steps so far and map information generated so far exists in the map DB **110**, the local map generation unit **108** generates the local map data regarding the vicinity of the own position of the mobile object **10** from these pieces of map information.

(Step S**17**)

[0060] In step S**17**, the position estimation unit **107** searches for the feature values extracted in the step S**13** and the corresponding points in the local map data generated in the step S**16** respectively corresponding to the feature values and makes the association between each other.

(Steps S**18** and S**19**)
[0061] In step S**18**, the position estimation unit **107** calculates a posture that minimizes the evaluation value, obtained by the evaluation function between feature values associated in the step S**17**, by the iteration method. When the calculation result is not less than or equal to a previously set threshold value (No in step S**19**), the position estimation unit **107** executes the processing in the step S**17** again, makes the association between feature values based on the estimated posture calculated most lately, and executes the processing in the step S**18**. When the calculation result has become less than or equal to the previously set threshold value (Yes in the step S**19**), the process advances to step S**20**.
(Step S**20**)
[0062] In the step S**20**, the map generation unit **109** performs the coordinate transformation on the distance measurement data acquired by the distance measurement data acquisition unit **100** based on the posture obtained when the calculation result in the step S**18** fell below the previously set threshold value or the predetermined number of trials was exceeded.
(Step S**21**)
[0063] In step S**21**, the map generation unit **109** extends the map information by adding the distance measurement data after undergoing the coordinate transformation in the step S**20** to the map DB **110**.
(Step S**22**)
[0064] In step S**22**, the position estimation unit **107** updates the own position of the mobile object **10** from the previous step based on the posture obtained in the step S**18**.
<1-3> Effect
[0065] As described above, the position estimation device **11** according to the first embodiment applies a weight to the evaluation value at the time of the position estimation by assigning weights to the feature values. Therefore, the situation of falling into a local solution at the time of the position estimation caused by part of the feature points can be made unlikely to occur even in an environment in which there is a bias in the distribution of the feature points in each region or in an environment in which the feature is monotonous.
[0066] Further, the position estimation device **11** according to the first embodiment performs the weighting by using the posture information estimated by using the feature values and is thereby capable of appropriately making the data association between frames and further inhibiting the occurrence of the situation in which the posture estimation process falls into a local solution.
<2> Second Embodiment
[0067] While the position estimation device is mounted on a vehicle as the mobile object in the first embodiment, a position estimation device in a second embodiment is mounted on a three-dimensional measurement device as the mobile object. FIG. **8** is a diagram showing an example of a case where a position estimation device **21** according to the second embodiment is mounted on a three-dimensional measurement device **20**. In FIG. **8**, the three-dimensional measurement device **20** includes a distance measurement sensor **22**, a condition sensor **23** including an inertial sensor, the position estimation device **21**, and a holding unit **24**. The three-dimensional measurement device **20** may be equipped with a GNSS receiver. The position estimation device **21** has a configuration similar to the position estimation device **11** according to the first embodiment.
[0068] For example, the three-dimensional measurement device **20** is a measurement device for measuring the shape of a structure such as land, a road, a tunnel or a building or a detection device for detecting the change in the shape of a cliff, a mountain or the like. Further, since measurement while moving is performed in the three-dimensional measurement, the three-dimensional measurement device **20** is mounted on a work vehicle or is held and operated by a worker. The distance measurement sensor **12** described in the first embodiment can be used as the distance measurement sensor **22**. Similarly, the condition sensor **13** described in the first embodiment can be used as the condition sensor **23**. The position estimation device **21** is used for estimating the

posture of the three-dimensional measurement device **20** and is capable of adjusting parameters to suit measurement properties of the three-dimensional measurement device on the basis of the configuration described in the first embodiment. The holding unit **24** is a structure for holding the three-dimensional measurement device **20**, such as a stand for fixing the three-dimensional measurement device **20** to the work vehicle or a handle grip used for gripping the three-dimensional measurement device **20** with a hand, for example.

[0069] With the configuration in the second embodiment, the situation of falling into a local solution at the time of the position estimation caused by part of the feature points can be made unlikely to occur even in an environment in which there is a bias in the distribution of the feature points in each region or the feature is monotonous, such as flat land, a cliff, or a tunnel. Accordingly, the measurement accuracy of the three-dimensional measurement device can be increased.

DESCRIPTION OF REFERENCE CHARACTERS

[0070] **10**: mobile object, **11**: position estimation device, **12**: distance measurement sensor, **121**: LiDAR, **122**: camera, **123**: millimeter-wave radar, **13**: condition sensor, **15**: GNSS receiver (position information receiver), **20**: three-dimensional measurement device (mobile object), **21**: position estimation device, **22**: distance measurement sensor, **23**: condition sensor, **24**: holding unit, **31**: processor, **32**: memory, **33**: storage device, **34**: input-output interface, **100**: distance measurement data acquisition unit, **101**: feature extraction unit, **102**: posture information calculation unit, **103**: feature value weight determination unit, **104**: posture accumulation unit, **105**: coordinate axis transformation unit, **106**: preliminary posture integration unit, **107**: position estimation unit, **108**: local map generation unit, **109**: map generation unit, **110**: map DB.

Claims

1. A position estimation device that estimates a position of a mobile object provided with a distance measurement sensor that detects a surrounding environment, the position estimation device comprising: processing circuitry to extract a plurality of feature points from distance measurement data outputted from the distance measurement sensor to estimate restriction information indicating a direction in which posture assumed by a feature value of each of the plurality of feature points is restricted by using a SHOT method, when calculating the posture of the distance measurement sensor based on the plurality of feature points; to determine a plurality of weights, to be respectively assigned to the plurality of feature points, based on the restriction information indicating a restriction direction in which the posture is restricted; and to calculate a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying a plurality of evaluation values representing differences by the plurality of weights is minimized, the differences being differences between the plurality of feature points of the distance measurement data and a plurality of corresponding points respectively corresponding to the plurality of feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object by using the rotation amount and the translation amount.

2. The position estimation device according to claim 1, wherein the processing circuitry uses position posture information, obtained by integrating condition data outputted from a condition sensor included in the mobile object with position data outputted from a position information receiver included in the mobile object, as an initial value in matching between the plurality of feature points and the plurality of corresponding points.

3. The position estimation device according to claim 1, wherein the mobile object is a vehicle.

4. The position estimation device according to claim 1, wherein the mobile object is a three-dimensional measurement device.

5. A position estimation method to be executed by a position estimation device that estimates a position of a mobile object provided with a distance measurement sensor that detects a surrounding environment, the method comprising: extracting a plurality of feature points from distance measurement data outputted from the distance measurement sensor; estimating restriction information indicating a direction in which posture assumed by a feature value of each of the plurality of feature points is restricted by using a SHOT method, when calculating the posture of the distance measurement sensor based on the plurality of feature points; determining a plurality of weights, to be respectively assigned to the plurality of feature points, based on the restriction information indicating a restriction direction in which the posture is restricted; and calculating a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying a plurality of evaluation values representing differences by the plurality of weights is minimized, the differences being differences between the plurality of feature points of the distance measurement data and a plurality of corresponding points respectively corresponding to the plurality of feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object by using the rotation amount and the translation amount.

6. A non-transitory computer-readable storage medium for storing a position estimation program that causes a computer, estimating a position of a mobile object provided with a distance measurement sensor that detects a surrounding environment, to execute: extracting a plurality of feature points from distance measurement data outputted from the distance measurement sensor; estimating restriction information indicating a direction in which posture assumed by a feature value of each of the plurality of feature points is restricted by using a SHOT method, when calculating the posture of the distance measurement sensor based on the plurality of feature points; determining a plurality of weights, to be respectively assigned to the plurality of feature points, based on the restriction information indicating a restriction direction in which the posture is restricted; and calculating a rotation amount and a translation amount of the distance measurement data so that a sum of values obtained by respectively multiplying a plurality of evaluation values representing differences by the plurality of weights is minimized, the differences being differences between the plurality of feature points of the distance measurement data and a plurality of corresponding points respectively corresponding to the plurality of feature points in stored map information or previously measured distance data, and to estimate the position of the mobile object by using the rotation amount and the translation amount.