

TITLE OF THE INVENTION

ROBOT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a robot capable of traveling autonomously, and particularly relates to a robot that travels autonomously based on map information.

2. Description of the Related Art

A robot capable of traveling autonomously is configured to collect surrounding environment information, using sensors (cameras, etc.) incorporated in the robot, to estimate the current position and traveling route of the robot and travel according to the estimated position and path.

Generally, GPS signals are used in many cases to estimate the current position of the robot. However, position detection by a robot used in buildings may end up in insufficient in accuracy by GPS signals, posing a problem that the robot is unable to estimate an accurate position. To deal with this problem, a method has been proposed by which objects in images captured by sensing devices, etc., such as cameras, incorporated in the robot (captured images), are compared with (matched against) objects shown in maps (map information) and the current

position is estimated from the result of the comparison.

The accuracy of estimating the current position by this method depends on, for example, the accuracy and volume of collected image information on the surroundings. Plenty of collected image information allows accurate estimation of the current position, which case; however, it requires a greater amount of map information to compare with. In particular, a guide robot used in a building needs a lot of map information because the robot moves between multiple floors using an elevator.

To have a lot of map information, the robot downloads map information for estimating the current position from an external storage device, such as a hard disk, and stores the map information temporarily. A controller of the robot thus needs a large-capacity memory (RAM). In addition, to process a lot of map information, the robot needs a sufficient processing time. Because of these requirements, controlling the robot's traveling becomes troublesome, which is by no means preferable from the viewpoint of operation/control of the robot.

As a solution to such a problem, for example, JP 2017-21570 A (Patent Literature 1) discloses the following technique. A plurality of pieces of divided map information are stored in an external storage device, and multiple floor map information, which is created by

grouping pieces of divided map information on two or more floors into one piece of information, is read out of the external storage device and is written to a main memory (e.g., RAM). A traveling route generating unit generates a traveling route of the robot to a preset destination, referring to the multiple floor map information stored in the main memory.

When the robot moves to a different floor, therefore, the robot does not have to read much map information from the external storage device. In addition, because information to read is divided pieces of map information, the occurrence of a waiting time that results when map information is written (loaded) onto the main memory can be suppressed. Hence, the robot is allowed to move smoothly to a different floor

SUMMARY OF THE INVENTION

In such a robot, to obtain the traveling route, a calculation means (CPU) reads divided map information from the main memory and executes a calculation of estimating the current position, referring to the read divided map information. As the robot travels, the calculation means switches the current divided map information to new divided map information, reads the new divided map information, and executes a calculation of estimating the current position,

referring to the read divided map information. The calculation means executes these series of processes in sequence.

Now reading divided map information from the main memory and estimating the current position takes a given time (which will be referred to as "map switching time" in some cases). During the map switching time for switching divided map information and re-reading divided map information to estimate the current position in accordance with the robot's traveling status, therefore, the robot is not allowed to travel because of the need to ensure its safety. It is necessary that during the map switching time, the current position be estimated with reference to divided map information as the robot is kept stopped. In general, the greater the amount of map information is, the longer the stoppage time of the robot becomes.

In this manner, when divided map information is switched to be referred to new divided map information in order to estimate the current position in accordance with the robot's traveling status, the traveling robot is intentionally put to a stop, which creates an unnecessary waiting time. Besides, the robot is not always equipped with a memory with a capacity accommodating a large amount of map information, and reducing the memory capacity of the main memory as much as possible is an existing demand.

A main object of the present invention is to provide a robot that in its traveling to a destination, suppresses the occurrence of an unnecessary waiting time that results when the traveling robot is intentionally stopped to estimate its current position at the time of divided information switching.

An aspect of the present invention provides a robot that travels to a destination distant away from the robot across multiple floors, using an elevator, the destination being determined by a control mean. The control means includes: a getting-in/getting-off area map information loading means that before the robot travels to a boarding floor elevator hall, loads at least divided map information on the vicinity of the boarding floor elevator hall and divided map information on the vicinity of a destination floor elevator hall onto a memory; a navigation means that determines a traveling route leading from a current position to the destination, using the divided map information on the vicinity of the boarding floor elevator hall and the divided map information on the vicinity of the destination floor elevator hall, both the divided map information being stored in the memory; a travel time estimating means that estimates a travel time required for traveling to a given stop point at which the robot is intentionally put into a stopped state in a traveling route

leading from the boarding floor elevator hall to the destination floor elevator hall; a map switching time estimating means that estimates a map switching time that is taken from a point of reading the divided map information on the vicinity of the destination floor elevator hall to a point of estimating the current position when the divided map information on the vicinity of the boarding floor elevator hall is switched to the divided map information on the vicinity of the destination floor elevator hall; and a map information switching means that judges a relationship between the travel time and the map switching time and that determines the stop point at which the divided map information on the vicinity of the boarding floor elevator hall is switched to the divided map information on the vicinity of the destination floor elevator hall.

According to the present invention, in controlling the robot that travels toward the destination, the traveling robot is not intentionally stopped at the time of divided map information switching. This suppresses the occurrence of an unnecessary waiting time that is spent for estimating the current position with reference to divided map information.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a configuration diagram showing a configuration of a robot to which the present invention is applied;

Fig. 2A is a flowchart for explaining the first half of a divided map information switching procedure according to an embodiment of the present invention;

Fig. 2B is a flowchart for explaining the second half of the divided map information switching procedure according to the embodiment of the present invention;

Fig. 3A is a flowchart for explaining a procedure of a switching process A of Fig. 2B;

Fig. 3B is a flowchart for explaining a procedure of a switching process B of Fig. 2B;

Fig. 3C is a flowchart for explaining a procedure of a switching process C of Fig. 2B;

Fig. 4 is an explanatory diagram of a relationship between a map size and a map switching time;

Fig. 5 is an explanatory diagram of operations of arriving at a place in front of an elevator on the boarding floor and getting off the elevator on the destination floor;

Fig. 6 is an explanatory diagram of a process of detecting the frontage of an elevator hall;

Fig. 7 is an explanatory diagram of a result of detection of the frontage; and

Fig. 8 is an explanatory diagram of an operation carried out according to the embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of the present invention will now be described in detail with reference to the drawings. The present invention, however, is not limited to the embodiment described below, and various modifications and applications made within the technical concept of the present invention are included in the scope of the present invention.

Fig. 1 depicts a configuration of a robot 10 capable of traveling autonomously, to which the present invention is applied. This robot 10 drives at least two driving wheels 11 out of four wheels, and determines a traveling direction by two steering wheels 12, which are the other two wheels of the four wheels.

A signal receiving unit 13 included in the robot 10 receives various external signals (sensor signals, etc.). This signal receiving unit 13, for example, receives input of GPS signals, with which the current position is estimated in a global absolute coordinate system. The signal receiving unit 13 may have a function of receiving map information from an external server.

The signal reception unit 13 may receive input of RTK-GPS signals that allow estimation of the current position more precise than the estimation with GPS signals. The signal reception unit 13 may receive also input of signals from a quasi-zenith satellite, signals from a radio beacon fixed at a known position, signals from sensors that make position estimation with relative coordinates, such as a wheel encoder, an IMU, and a gyro, and signals carrying shape information on the shape, size, height, etc., of an object in a traveling environment. In short, input signals to the signal receiving unit 13 are not limited to specific signals, providing that the signals can be used for estimation, control, and recognition of the current position of the robot 10.

A sensor 14 is, for example, a still camera or a video camera. The camera (sensor) 14 may be a monocular camera or a compound-eye camera. The camera (sensor) 14 may also be a laser sensor, such as a lidar. In short, the camera (sensor) 14 is not limited to any specific type of camera, providing that the camera 14 is capable of capturing information of the shape of an object (pillar, wall, article, etc.) present in a traveling route. In the following, the sensor 14 will be explained as a camera.

A camera 14a is disposed, for example, on a front part of the robot 10, and photographs in the forward

direction of the robot 10. The camera 14a can, therefore, take an image of a distant view ahead of the robot 10. Other cameras 14b to 14n are arranged in locations different from the location of the camera 14a, and photograph in directions different from the direction of photographing of the camera 14a, thus taking images of different areas. The sensor 14b may be disposed, for example, on a rear part of the robot 10 in such a way as to face downward, and the camera 14b may take an image of a view around the rear part of the robot 10. An image taken by the camera serves as image information.

When the camera 14 is a monocular camera, if the floor surface is flat, a pixel position on the image and an actual position (x, y) on the ground have a constant relationship, from which the distance from the camera 14 to a feature point can be geometrically calculated. When the floor surface is not flat, the distance to the feature point can be estimated, based on an amount of travel in time sequence of the feature point on the image and on an amount of travel of the robot 10.

When the camera 14 is a stereo camera, the distance to the feature point on the image can be geometrically measured with sufficient accuracy. When the camera 14 is a laser sensor, information of the shape of a distant object can be acquired more accurately. In the following, a case

where the camera 14 is provided as the above camera or laser sensor will be described. The camera 14, however, may be provided as a camera different from the above camera (a camera with a wide-angle lens, a TOF camera, or the like).

Images taken by the cameras 14a to 14n at a certain point of time may be different from each other. For example, the camera 14a takes an image of a distant view ahead of the robot 10, in which case such features as an object of a solid shape or a landmark for position estimation may be extracted from the image of the distant view. The camera 14b may take an image of a view or object nearby, such as the floor surface around the robot 10.

The cameras 14a to 14n may be set on the robot 10 under a condition in which they are not affected by environmental disturbance elements, such as rain and sunlight. For example, whereas the camera 14a is disposed on the front part of the robot 10 in such a way as to face forward, the camera 14b may be disposed on the rear part of the robot 10 in such a way as to face rearward or downward.

In this configuration, for example, when raindrops fall on the lens of the camera 14a in a rainy weather, raindrops hardly fall on the lens of the camera 14b because it faces the direction opposite to the forward direction, i.e., the direction of travel of the robot 10, or the

downward direction. Even in a case where an image taken by the camera 14a is unclear due to the influence of raindrops, therefore, an image taken by the camera 14b is hardly affected by the raindrops. In another case where an image taken by the camera 14a is unclear due to the influence of sunlight, an image taken by the camera 14b is clear.

The camera 14a and the cameras 14b to 14n may take images under different photographing conditions (different diaphragm values, white balances, cycles, etc.). For example, the robot 10 is equipped with a camera with parameters adjusted for photographing in a bright place and with a camera with parameters adjusted for photographing in a dark place. This allows the robot 10 to acquire quality images, regardless of whether a photographing space is bright or dark.

The control unit CU includes a control processing unit 15, a volatile memory (RAM) 17, and a display control unit 18. The control unit CU is provided with map information sent from an external storage device 16, which is a hard disk or a flash memory.

The camera 14a and the cameras 14b to 14n each take an image upon receiving an instruction to start photographing from the control processing unit 15 making up the control unit CU or at regular time intervals. Data of

a taken image, a time at which an image is taken, or the like are stored in the volatile memory (RAM) 17. Further, map information for drawing a map and estimating the current position is written to the volatile memory (RAM) 17, the map information being written by the external storage device 16.

Different control tasks may be executed, using images taken by the camera 14a and the cameras 14b to 14n. For example, the position of the robot 10 is estimated, based on information of images taken by the camera 14a and camera 14b, and an obstacle is detected by the camera 14c and camera 14d. What is needed after all is that the control processing unit 15 can control the robot 10, based on information of taken images acquired from the camera 14a and the cameras 14b to 14n.

Furthermore, when the CPU of the control processing unit 15 is able to process only the single thread tasks, the control processing unit 15 processes pieces of information acquired from the camera 14a and the cameras 14b to 14n in the order of information from the camera 14a and information from the cameras 14b to 14n. When the CPU of the control processing unit 15 is able to process multithread tasks, on the other hand, the control processing unit 15 can simultaneously process pieces of information acquired from the camera 14a and the cameras

14b to 14n.

The control processing unit 15 processes information acquired by the signal receiving unit 13 and the camera 14 to calculate the position and the amount of travel of the robot 10. For example, the control processing unit 15 calculates an amount of travel of the robot 10, based on images taken in time sequence by the camera 14, and adds the amount of travel to a position of the robot 10 in the past to estimate the current position of the robot 10. The control processing unit 15 may extract a feature point from each piece of information acquired in time sequence.

The control processing unit 15 further extracts the same feature point from pieces of information of taken images that follow a piece of information from which the feature point has been extracted. By tracking the feature point, the control processing unit 15 is able to calculate the amount of travel of the robot 10. The control processing unit 15 can calculate the shape of an object on a traveling route of the robot 10, using a simultaneous localization and mapping (SLAM) method or a structure from motion (SFM) method.

The control processing unit 15 carries out map matching of comparing an image taken by the camera 14 with shape information of an object on the traveling route, the shape information being created in advance, using an

iterative closest point (ICP) method, thus estimating the current position of the robot 10. The control processing unit 15 processes information acquired from the external storage device 16. The control processing unit 15 may perform display according to a calculated position and an amount of travel, or may output a signal related to control of the robot 10.

The control processing unit 15, for example, processes an image taken by the camera 14 during traveling of the robot 10, thereby detecting an obstacle, and processes an image taken by the camera 14 during traveling of the robot 10, thereby recognizing a preset landmark.

The control processing unit 14 receives map information from the external storage device 16, via the signal receiving unit 13, and loads the received map information onto the volatile memory (RAM) 17, which stores the incoming map information. The loaded map information is pieces of divided map information created in advance at the external storage device 16. In some cases, however, the robot 10 may create these pieces of divided map information by dividing map information into pieces of information each having a given information volume.

The control processing unit 15 outputs an instruction on a travel speed to the robot 10, based on an information processing result. For example, the control

processing unit 15 can output a command to increase, decrease, or maintain the travel speed of the robot 10, according to the resolution of an object in a taken image, the number of outliers among feature values in the taken image, or the type (method) of information processing.

The volatile memory (RAM) 17 is a main storage device (main memory) of the robot 10, and may include an auxiliary storage device, such as a storage different from the volatile memory (RAM) 17. The control processing unit 15 carries out various types of information processing, based on of various pieces of information stored in the volatile memory (RAM) 17, information acquisition times, etc. By this information processing, for example, intermediate information is created and is stored in the volatile memory (RAM) 17. The intermediate information may be used for processes by the control processing unit 15 and for determinations or other processes as well.

The display control unit 18 carries out control to display status information on the robot 10 and a control operation to execute next. The display control unit 18 displays, for example, information obtained by the camera 14. The display control unit 18 can display a process result or an instruction from the control processing unit 15, and can display, for example, a destination or a destination floor to which the robot 10 travels next. The

display control unit 18 can display an obstacle nearby, which is recognized by the camera 14. The display control unit 18 can display a loaded map.

A bus line 19 is composed of an inter equipment bus (IEBUS), a local interconnect network (LIN), or a controller area network (CAN).

The external storage device 16 stores map information including space information on objects, etc., on the traveling route the robot 10 travels. The map information in the external storage device 16 indicates, for example, the shapes and positions of objects (walls, pillars, signboards, lights, tables, chairs, etc.) present on the traveling route of the robot 10, which is caused to travel by a navigation means included in the control processing unit 15. The external storage device 16 may be provided in an external server. In such a case, the map information can be transmitted by wireless communication.

Each piece of map information in the external storage devices 16 may be expressed by a mathematical formula. For example, line information may be expressed not as a plurality of points but by the slope of a line and intercepting. Pieces of map information in the external storage device 16 may be not distinguished from each other and expressed as a group of points as a whole. The group of points may be expressed as 3D coordinates (x, y, z), 4D

coordinates (x, y, z, color element), etc. What is required after all is that space information on the traveling route is acquired from the current position of the robot 10 by the camera, etc., and is matched against loaded map information. As long as this process is carried out, the form of expression of the map information in the external storage device 16 is not limited to any specific form.

When receiving an instruction to start map information acquisition, the instruction coming from the control processing unit 15, the external storage unit 16 extracts required divided map information from the map information stored in the external storage unit 16 and transfers (loads) the divided map information to the volatile memory (RAM) 17 of the robot 10.

In this case, when the external storage device 16 is an external server not incorporated in the robot 10, the robot 10 is connected to a storage device of the external server via the signal receiving unit 13. The robot 10 is connected to the storage device of the external server through, for example, wireless communication in a local area network (LAN) or a wide area network (WAN). When the external storage device 16 is incorporated in the robot 10, the map information is transmitted and received via the bus line 19. The map information in the external storage

device 16 is made up of pieces of divided map information created by dividing the map information in advance.

When receiving a loading instruction from the control processing unit 15, the external storage device 16 transmits divided map information on the traveling route of the robot 10, the divided map information being stored in the external storage device 16, to the volatile memory (RAM) 17. The external storage device 16 may also transmit, as map information, pieces of divided map information created in advance, or some pieces of divided map information.

The control processing unit 15 has a function of switching current divided map information loaded onto the volatile memory (RAM) 17 to next divided map information at a given stop point on the traveling route. For example, when the robot 10 travels the traveling route, a stop point where the robot intentionally stops traveling is determined, and divided map information is switched using a time during which the robot stays stationary. This allows divided map information switching to be carried out without affecting the robot's traveling. The stop point is not specified in particular. When an elevator car moves between different floors, an elevator hall on a boarding floor, the elevator car interior, and an elevator hall on a destination floor are each equivalent to the stop point.

A process flow showing a flow of processes of switching divided map information by the control processing unit 15 will then be described with reference to Fig. 2. It should be noted that the robot 10 is caused to travel on the traveling route by the navigation means included in the control processing unit 15.

Map switching in a case where the robot 10 moves to a different floor is important. Description of this embodiment will therefore be focused on this point. The process flow to be described below can be understood as a function or a means executed by a program.

<<Step S10>> (Destination Setting Means)

At step S10, a destination is set when the robot 10 moves to a different floor. The control processing unit 15 can set a destination, based on a signal received from the signal receiving unit 13. For example, when a user calls the robot 10, using a cellular phone, or wants to cause the robot 10 to travel to a specific destination, the user sends the destination to the robot 10, thereby setting the destination.

When the signal receiving unit 13 receives the destination sent by the user, the control processing unit 15 temporarily stores the destination in the volatile memory (RAM) 17 and then accesses the volatile memory (RAM) 17 to set the stored destination. When destination setting

is completed, the process flow proceeds to step S11.

In this embodiment, the control processing unit 15 controls traveling of the robot 10, based on space information (map information) on the traveling route, the space information being acquired by the camera 14. For example, when an obstacle, such as an object, is present on the traveling route of the robot 10, the control processing unit 15 recognizes the obstacle, based on an image taken by the camera 14, and avoids the obstacle.

<<Step S11>> (Position Estimating Means)

At step S11, the current position of the robot 10 is estimated from an image taken by the camera. The robot 10 is currently at a certain position on the boarding floor. This current position is estimated by, as described above, matching the taken image against divided map information indicating the position of the robot (map matching). When this current position estimation is completed, the process flow proceeds to step S12.

Map matching is a process of determining a degree of matching of an object in the taken image and an object shown in map information and, when a given degree of matching is reached, estimating the position of the object indicated in the image and map information to be the current position.

<<Step S12>> (Getting-In/Getting-Off Area Map

Information Loading Means)

At step S12, divided map information on the vicinity of the elevator hall on the boarding floor is downloaded from the external storage device 16. In the vicinity of the elevator hall on the boarding floor, the robot 10 temporarily stops frequently in order to avoid people waiting for the elevator and an obstacle near the elevator hall. The vicinity of the elevator hall on the boarding floor is therefore set in advance as the given stop point. A place in front of the elevator entrance is a place where the robot 10 waits for the elevator car to arrive, and is therefore also set in advance as the given stop point.

Divided map information on the vicinity of the elevator hall on the boarding floor is loaded by an instruction from the control processing unit 15 such that the external storage device 16 transmits the divided map information on the vicinity of the elevator hall on the boarding floor to the volatile memory (RAM) 17, which stores the divided map information temporarily. When loading of the divided map information on the vicinity on the elevator hall on the boarding floor is completed, the process flow proceeds to step S13.

<<Step S13>> (Getting-In/Getting-Off Area Map Information Loading Means)

At step S13, divided map information on the vicinity

of the elevator hall on the destination floor is downloaded from the external storage device 16. In the vicinity of the elevator hall on the destination floor, the robot 10 temporarily stops frequently in order to avoid people waiting for the elevator and an obstacle near the elevator hall, as does in the vicinity of the elevator hall on the boarding floor. The vicinity of the elevator hall on the destination floor is therefore set in advance as the given stop point.

Divided map information on the vicinity of the elevator hall on the destination floor is loaded by an instruction from the control processing unit 15 such that the external storage device 16 transmits the divided map information on the vicinity of the elevator hall on the destination floor to the volatile memory (RAM) 17, which stores the divided map information temporarily. When loading of the divided map information on the vicinity of the elevator hall on the destination floor is completed, the process flow proceeds to step S14.

To move from the boarding floor to the destination floor, the robot 10 gets in the elevator car. This state of being in the elevator car is also set as the given stop point.

<<Step S14>> (Navigation Means)

At step S14, a travel plan (route search) of the

robot 10 is set up. This travel plan is a plan for determining a traveling route for the robot 10 to travel, from the destination set at step S10 and the current position estimated at step S11. Route search is carried out typically by a Dijkstra method but is not limited to this method. Other route search algorithms may also be adopted. When the traveling plan is completed, the process flow proceeds to step S15.

<<Step S15>> (Travel Time (Waiting Time) Estimating Means)

At step S15, a waiting time (TW) for the robot 10 to wait for the elevator car at the elevator hall on the boarding floor is estimated. In this case, the robot 10 can determine the waiting time (TW) for waiting for the elevator car at the elevator hall on the boarding floor, from information on an operation status of the elevator car, the information being acquired from an elevator controller. The elevator controller transmits the information on the operation status of the elevator car to the robot 10 through wirelessly communication. In another case, the waiting time (TW) for waiting for the elevator car can be estimated from waiting times in the past, using a statistical method.

When the waiting time (TW) for waiting for the elevator car at the elevator hall on the boarding floor has

been estimated, the process flow proceeds to step S16.

<<Step S16>> (Moving Time (Boarding Time) Estimating Means)

At step S16, a travel time (TM) in which the robot 10 stays in the elevator car in a process of moving from the boarding floor to the destination floor is estimated. The travel time can be determined in advance, and is determined, basically, based on a difference in the number of floors between the boarding floor and the destination floor. The more the difference in the number of floors is, therefore, the longer the travel time is. However, the elevator car may stop at a floor that exists between the boarding floor and the destination floor. It is therefore preferable that the travel time be determined with such a case being taken into consideration. In this case, the travel time can be determined by a statistical method, as in the case of estimating the time-to-wait.

When the travel time (TM) in which the robot 10 stays in the elevator car when moving from the boarding floor to the destination floor is estimated, the process flow proceeds to step S18.

<<Step S17>> Map Switching Time Estimating Means)

At step S17, a map switching time (Tn) for switching divided map information is estimated. This map switching time is a time the control processing unit 15 takes to

estimate the current position, referring to divided map information already loaded in the volatile memory (RAM) 17.

In other words, it means a time that the control processing unit 15 takes from reading next divided map information to estimating the current position when switching from the current divided map information (in this embodiment, divided map information on the vicinity of the elevator hall on the boarding floor) to the next divided map information (in this embodiment, divided map information on the vicinity of the elevator hall on the destination floor).

Fig. 4 shows a relationship between divided map information and a map switching time. In Fig. 4, the horizontal axis represents a map size, which is an amount of information a divided map provides, and the vertical axis represents a map switching time. A size/time characteristic line (F) represents a relationship between the size of the divided map and the map switching time. To facilitate understanding, the size/time characteristic line (F) is shown as a straight line. The size/time characteristic line (F), however, may be expressed in the form of a curve or a polynomial.

The size/time characteristic line (F) can be determined experimentally, based on the size of a divided map and on a time the control processing unit 15 takes to

estimate the current position, referring to information of the divided map. The size/time characteristic line (F) can also be determined logically, based on the calculation speed of the control processing unit 15 or on the transmission speed of the bus line 19.

In short, any method by which a time to take to estimate the current position from the switched divided map can be calculated is applicable. In Fig. 4, a divided map size (S_n) is the size of a specific divided map, and a map switching time (T_n) is output given by substituting the divided map size (S_n) in the size/time characteristic line (F). This indicates that when the size of a divided map acquired by referring to the volatile memory (RAM) 17 is known, the map switching time (T_n) can be estimated.

The map switching time (T_n) may be determined not by calculation but by reading the map switching time (T_n) from a table listing map switching times and divided map sizes. When the map switching time (T_n) for switching divided map information is estimated, the process flow proceeds to step S18.

<<Step S18>> (Map Information Switching Means)

At step S18, a time relationship between the map switching time (T_n) estimated at step S17 and the waiting time (T_w) estimated at step S15 is determined. In other words, whether the map switching time (T_n) is longer than

the waiting time (TW) is determined.

When the map switching time (Tn) is determined to be longer than the waiting time (TW), it is concluded that the robot cannot estimate its current position by referring to divided map information on the vicinity of the elevator hall on the destination floor within the time for waiting for the elevator on the boarding floor after leaving the start point. The process flow then proceeds to step S19.

When the map switching time (Tn) is determined to be shorter than the waiting time (TW), on the other hand, it is concluded that the robot can estimate its current position by referring to divided map information on the vicinity of the elevator hall on the destination floor within the time for waiting for the elevator on the boarding floor after leaving the start point. The process flow then proceeds to step S22.

<<Step S19>> (Map Information Switching Means)

At step S19, a time relationship between the map switching time (Tn) estimated at step S17 and the travel time (TM) for traveling in the elevator car estimated at step S16 is determined. In other words, whether the map switching time (Tn) is longer than the travel time (TM) for traveling in the elevator car is determined.

When the map switching time (Tn) is determined to be longer than the travel time (TM) for traveling in the

elevator car, it is concluded that the robot cannot estimate its current position by referring to divided map information on the vicinity of the elevator hall on the destination floor within the time for staying in the elevator car. The process flow then proceeds to step S20.

When the map switching time (T_n) is determined to be shorter than the travel time (T_M) for traveling in the elevator car, on the other hand, it is concluded that the robot can estimate its current position by referring to divided map information on the vicinity of the elevator hall on the destination floor within the time for staying in the elevator car. The process flow then proceeds to step S21.

<<Step S20>> (Map Information Switching Means)

At step S20, "process A", which will be described later, is executed. The "process A" is a process of arriving at the destination floor and estimating the current position, referring to divided map information on the vicinity of the elevator hall on the destination floor. Following execution of the "process A", the process flow comes to an end.

<<Step S21>> (Map Information Switching Means)

At step S21, a "process B", which will be described later, is executed. The "process B" is a process of estimating the current position, referring to divided map

information on the vicinity of the elevator hall on the destination floor, while staying in the elevator car. Following execution of the "process B", the process flow comes to an end.

<<Step S22>> (Map Information Switching Means)

At step S22, a time relationship between the map switching time (T_n) estimated at step S17 and the travel time (T_M) for traveling in the elevator car estimated at step S16 is determined. In other words, whether the map switching time (T_n) is longer than the travel time (T_M) for traveling in the elevator car is determined.

When the map switching time (T_n) is determined to be longer than the travel time (T_M) for traveling in the elevator car, it is concluded that the robot cannot estimate its current position by referring to divided map information on the vicinity of the elevator hall on the destination floor within the time for staying in the elevator car. The process flow then proceeds to step S23.

When the map switching time (T_n) is determined to be shorter than the travel time (T_M) for traveling in the elevator car, on the other hand, it is concluded that the robot can estimate its current position by referring to divided map information on the vicinity of the elevator hall on the destination floor within the time for staying in the elevator car or at the elevator hall on the boarding

floor. The process flow then proceeds to step S24.

<<Step S23>> (Map Information Switching Means)

At step S23, a "process C", which will be described later, is executed. The "process C" is a process of estimating the current position, referring to divided map information on the vicinity of the elevator hall on the destination floor, at the elevator hall on the boarding floor. Following execution of the "process C", the process flow comes to an end.

<<Step S24>> (Map Information Switching Means)

At step S24, the "process B" or "process C", which will be described later, is executed. Details of the "process B" and "process C" have been described above. Following execution of the "process B" or "process C", the process flow comes to an end.

Control steps preceding execution of the above "process A" to "process C" are pre-processing that is executed before the robot 10 starts traveling. The "process A" to "process C" will then be described specifically. The "process A", the "Process B", and the "Process C" are shown in Fig. 3A, Fig. 3B, and Fig. 3C, respectively.

[Process A] (switching divided map information at the elevator hall on the destination floor)

<<Step S30>>

At step S30, the robot 10 starts traveling to the vicinity of the elevator hall on the boarding floor, according to divided map information on the boarding floor where the robot 10 is present. The robot 10 travels in accordance with the traveling plan set at step S14. The robot 10 travels while estimating its current position. As the robot 10 is in this state, the process flow proceeds to step S31.

<<Step S31>>

At step S31, the robot 10 travels along the traveling route while estimating its current position, and determines whether the robot 10 has arrived at the vicinity of the elevator hall on the boarding floor. When determining that the robot 10 has arrived at the vicinity of the elevator hall on the boarding floor, the robot 10 stops temporarily because the vicinity of the elevator hall on the boarding floor is set as the given stop point. When the robot stops, the process flow proceeds to step S32.

<<Step S32>>

At step S32, a process of switching divided map information on the boarding floor to divided map information on the vicinity on the elevator hall on the boarding floor is executed. This is a process of switching divided map information on the current boarding floor to divided map information on the vicinity on the elevator

hall on the next boarding floor.

To carry out this map switching, the robot 10 stops traveling and intentionally comes to a temporary stop at the vicinity of the elevator hall on the boarding floor. In this case, when the above map switching time arises, it is not considered to be a waiting time. When map switching is completed, the process flow proceeds to step S33.

<<Step S33>>

At step S33, the robot 10 starts traveling toward the elevator entrance, based on the switched divided map information on the vicinity of the elevator hall on the boarding floor, while estimating the current position. When the robot 10 starts traveling, the process flow proceeds to step S34.

<<Step S34>>

At step S34, the robot 10 determines whether it has arrived at the place in front of the elevator entrance, based on the switched divided map information on the vicinity of the elevator hall on the boarding floor, while estimating the current position. When the robot 10 determines that it has arrived at the place in front of the elevator entrance, the process flow proceeds to step S35.

<<Step S35>>

At step S35, the robot 10 gets in the arriving elevator car, which then starts moving toward the

destination floor. At this step, however, if the frontage of the elevator entrance is narrow and an error in current position estimation at step 34 is large relative to the frontage, the robot 10 may not be able to get in the elevator car.

In this case, the robot 10 detects the width of the door of the elevator entrance, using the camera 14, and calculates the relative position of the robot 10 to the door, which allows the robot 10 to get in the elevator car. Details of this process of detecting the width of the door of the elevator entrance will be described later. When the robot 10 arrives at the destination floor, the process flow proceeds to step S36.

<<Step S36>>

At step S36, the robot 10 comes out of the elevator entrance to reach the elevator hall on the destination floor. Because the vicinity of the elevator hall on the destination floor is set as the given stop point, the robot 10 stops there temporarily. When the robot stops, the process flow proceeds to step S37.

<<Step S37>>

At step S37, inter-floor map information switching is executed. This is a process of switching divided map information on the vicinity of the elevator hall on the current boarding floor to divided map information on the

vicinity of the elevator hall on the next destination floor. To carry out this map switching, the robot 10 stops traveling and intentionally comes to a temporary stop at the elevator hall on the destination floor after getting off the elevator car. In this case, when the above map switching time arises, it is not considered to be a waiting time. When divided map information switching is completed, the process flow proceeds to step S38.

At this map information switching step, the robot 10 finds a safe stop point immediately after getting off the elevator car, based on information obtained by the camera 14, and switches the divided map information. One example of the safe stop point is, for example, a place near the wall of the elevator hall, where the robot 10 does not obstruct traffic of people. The safe stop point may be a predetermined specific place in each elevator hall.

<<Step S38>>

At step S38, the robot 10 starts traveling toward the destination, based on the switched divided map information on the vicinity of the elevator hall on the destination floor, while estimating the current position. Following this step at which the robot 10 starts traveling, the process flow comes to an end.

[Process B] (switching divided map information while staying in the elevator car)

This "process B" is a process of executing the inter-floor map switching of step S37 in a period between step S35 and step S36, in which period the robot stays in the elevator car. The robot staying in the elevator car is in a state of being intentionally stopped and remaining stationary. The elevator car interior is thus set as the given stop point. The details of the "process B" are the same as those of the "process A", and are therefore omitted in further description.

[Process C] (switching divided map information in the place in front of the elevator entrance on the boarding floor)

This "process C" is a process of executing the inter-floor map switching of step S37 in a period between step S34 and step S35, in which period the robot is in the place in front of the elevator entrance on the boarding floor. In the place in front of the elevator entrance, the robot 10 intentionally stops and waits the elevator car to arrive. The place in front of the elevator entrance is thus set as the given stop point. The details of the "process B" are the same as those of the "process A", and are therefore omitted in further description.

Behavior of the robot 10 in the case of its moving from the boarding floor to the destination floor according to the above process flows will then be described

supplementarily.

In Fig. 5, the vicinity of the elevator hall (EH1) on the boarding floor is an area where the robot 10 gets in the elevator car. It is assumed, for convenience, that the vicinity of the elevator hall (EH1) on the boarding floor is on the first floor of a building. An elevator car 20 is the elevator car that the robot 10 gets in to move from the boarding floor to the destination floor. The vicinity of the elevator hall (EHn) on the destination floor is the vicinity of the elevator hall on the destination floor for which the robot 10 is heading. It is assumed that the vicinity of the elevator hall (EHn) on the destination floor is on the n-th floor of the building. In this embodiment, the vicinity of the elevator hall means the elevator hall.

The robot 10 is present in the vicinity of the elevator hall (EH1) on the boarding floor, and a person 21 is present in the vicinity of the elevator hall (EHn) on the destination floor. Pieces of divided map information (M1), (M2),...(Mn) are respective pieces of divided map information on different floors of the building.

Now a case is assumed where the robot 10 moves from the first floor to the n-th floor by following an instruction from the control processing unit 15. The robot 10, at step S12, downloads the divided map information (M1)

on the vicinity of the elevator hall (EH1) on the boarding floor, and, at step S13, downloads the divided map information (Mn) on the vicinity of the elevator hall (EHn) on the destination floor.

The robot 10 then moves to a place in front of the elevator car 20 while referring to the divided map information (M1) on the vicinity of the elevator hall on the boarding floor. Subsequently, the robot 10 switches the divided map information (M1) to the divided map information (Mn) on the n-th floor, which is the destination floor.

Timing of this divided map information switching is determined, based on a time ($TG + TW$) the robot 10 takes to travel from the current position to the vicinity of the elevator hall (EH1) on the first floor and wait for arrival of the elevator car, on the travel time (TM) during which the robot 10 stays in the elevator car to move from the first floor to the n-th floor, and on the map switching time (Tn) shown in FIG. 4.

This has been described with reference to Fig. 2B. The robot 10 thus switches the divided map information (M1) on the vicinity of the elevator hall (EH1) on the boarding floor to the divided map information (Mn) on the vicinity of the elevator hall (EHn) on the destination floor when being stopped and waiting for the elevator car at the

elevator hall on the boarding floor, being stopped and staying in the elevator car, or being stopped at the elevator hall on the destination floor after getting off the elevator car.

A frontage detection process executed at step S35 will then be described. The robot 10 constantly carries out position estimation (step S11) at given time intervals. An error in this position estimation, however, becomes large in some cases, due to the influence of a travel environment or an obstacle. In particular, when the frontage of the elevator entrance is narrow and its position cannot be accurately estimated, the robot 10 may fail to go through the elevator entrance. To prevent such a case, the frontage detection process is necessary.

Figs. 6 and 7 depict a state in which the elevator car 20 arrives at the elevator hall and the door 22 of the elevator entrance is opened. The robot 10 takes an image of the elevator entrance, using the camera 14 set at a viewing angle (θ) relative to the elevator entrance.

When an error in the position of the robot 10 estimated at step S11 is large, the robot 10 is not able to go through the narrow door 22. To deal with this problem, the robot 10 turns left and right to measure distances to objects nearby including the door 22, using the camera 14.

Fig. 7 shows distances to objects nearby, the

distances being acquired by the camera 14 tuned left and right as the robot 10 turns left and right. Corners Cn are left and right corners of the door 22. The corners Cn are edges determined by calculating changes in the distances to the objects (in Fig. 7, the door 22 and the elevator car 20 are extracted and illustrated).

Data in Fig. 7 is structured into an image in which the corners Cn are calculated by a Harris corner detection (HCD) method. In short, what is required is to determine the position of the corners Cn. Referring to the detected relative position of the corners Cn, the robot 10 then gets in the elevator car 20, and gets off the elevator car on the destination floor.

When an error in the position of the robot 10 estimated at step S11 is large, the robot 10 gets in and off the elevator car 20 while carrying out the process indicated in Fig. 7. When an error in the position estimation is small, however, the robot 10 can get in and off the elevator car 20, depending on only the position estimated at step S11.

An error in position estimation can be determined, based on, for example, an error ellipse created by simultaneous localization and mapping (SLAM) carried out by the camera 14. When the error ellipse exceeds a preset threshold when the robot 10 gets in and off the elevator

car 20, the frontage detection process may be carried out. An error in position estimation may also be determined by a score of successful matching (distances to closest points) in an interactive closest point (ICP) algorithm carried out by the camera 14.

A rotation angle of the robot 10 that is needed for the frontage detection process can be calculated, for example, based on an error in the position of the robot 10 estimated at step S11 and on the viewing angle (θ).

Behavior of the robot 10 and a flow of reference to map information in the case where the robot 10 moves from the boarding floor to the destination floor will then be described. FIG. 8 shows a case where the robot 10 moves from the first floor, which is the current position, to the sixth floor, which is the destination.

In Fig. 8, the robot 10 travels on the floor surface (FL1) of the first floor. In this case, the robot 10 travels, referring to floor divided map information (M1F). When arriving at an elevator hall (EH1) on the first floor, the robot 10 travels to the elevator entrance, referring to division map information (M1H) on the elevator hall (EH1) on the first floor.

The robot 10 then gets in the elevator car and arrives at an elevator hall (EH6) on the sixth floor, from which the robot 10 travels, referring to divided map

information (M6H) on an elevator hall (EH6) on the sixth floor, and heads for the destination, referring to floor divided map information (M6F) on the sixth floor.

While executing the steps shown in Figs. 2B and 3A to 3C in correspondence to actions to take and referring to switched divided map information used for position estimation calculations, the robot 10 travels to the destination.

When the person 21 is present in the elevator hall (EH6) on the sixth floor, the robot 10 stops temporarily, and confirms from an image taken by the camera 14 that the person 21 is gone, and then moves to a safe place where the robot 10 switches to the divided map information (M6H) on the elevator hall (EH6).

As described above, a robot of the present invention travels to a destination distant away from the robot across multiple floors, using an elevator car, the destination being determined by a control mean. The control means includes: a getting-in/getting-off area map information loading means that before the robot travels to a boarding floor elevator hall, loads at least divided map information on the vicinity of the boarding floor elevator hall and divided map information on the vicinity of a destination floor elevator hall onto a memory; a navigation means that determines a traveling route leading from a current

position to the destination, using the divided map information on the vicinity of the boarding floor elevator hall and the divided map information on the vicinity of the destination floor elevator hall, both the divided map information being stored in the memory; a travel time estimating means that estimates a travel time required for traveling to a given stop point at which the robot is intentionally put into a stopped state in a traveling route leading from the boarding floor elevator hall to the destination floor elevator hall; a map switching time estimating means that estimates a map switching time that is taken from a point of reading the divided map information on the vicinity of the destination floor elevator hall to a point of estimating the current position when the divided map information on the vicinity of the boarding floor elevator hall is switched to the divided map information on the vicinity of the destination floor elevator hall; and a map information switching means that judges a relationship between the travel time and the map switching time and that determines the stop point at which the divided map information on the vicinity of the boarding floor elevator hall is switched to the divided map information on the vicinity of the destination floor elevator hall.

According to the present invention, in controlling

the robot that travels toward the destination, the traveling robot is not intentionally stopped at the time of divided map information switching. This suppresses the occurrence of an unnecessary waiting time that is spent for estimating the current position.

It should be noted that the present invention is not limited to the above-described embodiments but includes various modifications. For example, the above embodiments have been described in detail for facilitating understanding of the present invention, and are not necessarily limited to embodiments including all the constituent elements described above. Some constituent elements of a certain embodiment may be replaced with constituent elements of another embodiment, and a constituent element of another embodiment may be added to a constituent element of a certain embodiment. In addition, a constituent element of each embodiment may be deleted therefrom or be added to or replaced with a constituent element of another embodiment.

What is claimed is:

1. A robot that travels to a destination position distant away from the robot across multiple floors, using an elevator car, the destination position being determined by a control mean, wherein

the control means includes:

a getting-in/getting-off area map information loading means that before the robot travels to a boarding floor elevator hall, loads at least divided map information on vicinity of the boarding floor elevator hall and divided map information on vicinity of a destination floor elevator hall onto a memory;

a navigation means that determines a traveling route leading from a current position to the destination position, using the divided map information on the vicinity of the boarding floor elevator hall and the divided map information on the vicinity of the destination floor elevator hall, both the divided map information being stored in the memory;

a travel time estimating means that estimates a travel time required for traveling to a given stop point at which the robot is intentionally put into a stopped state in a traveling route leading from the boarding floor elevator hall to the destination floor elevator hall;

a map switching time estimating means that estimates a map switching time that is taken from a point of reading the divided map information on the vicinity of the destination floor elevator hall to a point of estimating the current position when the divided map information on the vicinity of the boarding floor elevator hall is switched to the divided map information on the vicinity of the destination floor elevator hall; and

a map information switching means that judges a relationship between the travel time and the map switching time and that determines the stop point at which the divided map information on the vicinity of the boarding floor elevator hall is switched to the divided map information on the vicinity of the destination floor elevator hall.

2. The robot according to claim 1, wherein the given stop point is the boarding floor elevator hall.

3. The robot according to claim 1, wherein the given stop point is an elevator car which the robot gets in.

4. The robot according to claim 1, wherein the given stop point is the destination floor elevator hall.

5. The robot according to claim 1, wherein

the given stop point is at least the boarding floor elevator hall, the elevator car which the robot gets in, and the destination floor elevator hall,

each of the travel times is at least a waiting time (TW) for the robot to wait at the boarding floor elevator hall and a boarding time (TM) in which the robot stays in an elevator car,

the map information switching means executes map information switching at the destination floor elevator hall when the map switching time (T_n) is longer than the waiting time (TW) and is longer than the boarding time (TM),

the map information switching means executes map information switching at the elevator car in which the robot stays when the map switching time (T_n) is longer than the waiting time (TW) and is shorter than the boarding time (TM),

the map information switching means executes map information switching at the boarding floor elevator hall when the map switching time (T_n) is shorter than the waiting time (TW) and is longer than the boarding time (TM), and

the map information switching means executes map information switching at the elevator car in which the robot stays or at the boarding floor elevator hall when the

map switching time (T_n) is shorter than the waiting time (T_w) and is shorter than the boarding time (T_m).