

**ROBOT SYSTEM**

The present invention relates to mobile robots with a navigation system utilizing inertia.

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A known mobile robot has used a step motor for moving to a desired destination. To reach any one point and then move toward another point, such a conventional mobile robot is turned to a desired direction by controlling a rotation number of the motor and then moved by a predetermined distance by use of a driving motor to be controlled by a microcomputer.

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In order to return to an original position (i.e. a start position), the robot must be moved from its present position toward the original position by using the rotation numbers of the step motor and the driving motor, the rotation numbers being stored within a memory means in the microcomputer at the time of the initial movement.

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In such a method for moving the robot as described above, however, when the robot is moved from one point toward another point, a moving course is determined based on the rotation numbers of the step motor and the drive motor. This means that a relative moving vector cannot be determined between the initial start position and the presently reached position. For this reason, when the robot is returned to the original start position after the robot has been moved to any point, the robot must be repeatedly moved back along its original course. Therefore, the conventional mobile robot has a problem that the robot cannot be returned along the shortest distance. Also, the moving direction of the robot is only determined based on the rotation

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numbers of the motors, so that if the rotation numbers of the robot are changed due to the friction resistance of a drive mechanism or obstacle, etc., and then the robot is deviated from a desired moving course, this state cannot be determined, whereby the deviated value from a normal moving course cannot be readily corrected.

In addition, the step motor is used as a means for precisely determining direction and controlling distance, causing a problem that the manufacturing cost is increased.

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An example of a conventional autonomous mobile robot is disclosed in U.S. Patent. No. 4,638,445 and is shown in Figure 1 of the accompanying diagrammatic drawings. This robot comprising a vision system 31 and a memory means for storing data entered from the vision system 31. A computer 33 processes data entered from the vision system 31 of the robot, and includes a first range plurality of transducer array 34 symmetrically disposed with an axis of symmetry of the mobile robot 30 and obtaining data relative to the position and the distance of an object in a workspace; and a second range plurality of transducer array 35 symmetrically disposed with the axis of the robot 30 with a different angle of view than the first transducer array with respect to the same object in the workspace and obtaining data relative to the position and the distance of an adjacent object in the workspace; means for sequentially transmitting signals determined by the computer 33 to each of the ranges of transducers; and, at least one auxiliary range transducer 36 for obtaining the position and distance information of an object deviated from the visual ranges of the first and second transducer arrays 34 and 35.

With this construction of the robot, there is an advantage that all of the obstacles encountered in the work space can be precisely and effectively measured since the rotation of the robot is controlled by using data information processed through software built in the microcomputer. On the  
5 contrary, the plurality of transducers of which the sensing areas are different from each other are disposed in two columns over the whole periphery on the top of the mobile robot and the auxiliary range transducer is also so disposed, thereby causing a complication of the construction and a rise of the manufacturing cost. Furthermore, software which is built in the computer and  
10 determines the moved distance and the rotative state will be complicated because of the plurality of transducers. If an erroneous operation occurs the robot will be deviated from its path, resulting in problems that it is impossible to protect the device from damage and to prevent accidents.

15 Preferred embodiments of the present invention aim to provide a mobile robot with a navigation system in which an optical sensor is attached on a compass utilizing inertia and forms a separate system for indicating a fixed direction and sensing a light regardless of the positional change of the robot so that when the robot is turned in direction and the robot is deviated  
20 from a normal path, the changed angle in direction can be discriminated, based on the amount of motion caused by moving of a cylindrical light-reflecting plate which surrounds the periphery of the compass.

Another aim is to provide a mobile robot with a navigation system  
25 utilizing inertia which can determine whether or not the robot is turned to the right or the left by using waveforms of light reflected from a reflecting plate.

Still another aim is to provide a mobile robot with a navigation system utilizing inertia in which a magnetic sensor is mounted on a general purpose motor so that the drive and directional change of the robot may be easily performed.

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According to a first aspect of the invention, there is provided a mobile robot comprising:

inertial navigation means for providing information indicating a moved  
10 angle between an initial start position of said robot and a current position, the information being used to plot a relative vector between said current and initial start positions, the inertial navigation means being further arranged to enable re-plotting of the vector following deviation of the robot due to the robot encountering an obstacle or the like in the course of its movement by  
15 providing new compensating information representing the moved angle;

means for measuring a moved distance of the robot;

directional turning means for turning the robot by a predetermined  
20 amount upon encountering an obstacle or upon the robot having moved by a predetermined distance: and

control means for controlling the directional turning means,  
determining moved angle on the basis of the information from the inertial  
25 navigation means, and calculating a shortest return distance for the robot to be returned to the initial start position.

Preferably, said inertial navigation means comprises a first light generating device, a first optical sensor, a compass and a cylindrical reflecting plate, the first light generating device and the first optical sensor being formed on the compass so as to rotate therewith relative to the cylindrical reflecting plate in accordance with the moved angle of the robot such that light emitted from the first light generating device and reflected by said reflecting plate is sensed by the first optical sensor and information therefrom representing the moved angle is provided to the control means.

10 Said means for measuring a moved distance may comprise a powerless wheel, a second light generating device and a second optical sensor, the powerless wheel being arranged to rotate with respect to said second light generating device and second light sensor about a central axis thereof, the powerless wheel having a plurality of radially spaced apart holes formed therein and the second optical sensor and second light generating device being  
15 arranged to be mounted on either side of the wheel such that as the wheel turns, light emitted from the second light generating device is able to pass through said holes and be detected by the second optical sensor, moved distance of the robot being measured on the basis of wave form pulses  
20 produced by the second optical sensor as light passes through the holes.

Said control means may comprise a magnet, a cylindrical plate and a magnet sensing sensor, the magnet and magnet sensing sensors being arranged for relative rotation in correspondence with turning motion of the robot, the  
25 control means determining the completion of a 90 degree turn at a moment when the magnet sensing sensor detects the presence of the magnet.

Preferably, said control means calculates the shortest return distance by using a triangulation method based on the initial start position and an actual point on the course of movement of the robot.

5 For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to Figures 2 to 9 of the accompanying diagrammatic drawings, in which:

Figure 2 is a plan view schematically showing one example of a mobile  
10 robot system embodying the present invention;

Figure 3 is a schematic side view of Figure 2;

Figure 4(a) and (b) are views showing a construction of a navigation  
15 system;

Figures 5(a) to (d) are views illustrating rotative direction and the measurement of angle in a navigation system;

20 Figures 6(a) and (b) are views showing a construction of a driving device in an example of a mobile robot embodying the present invention;

Figures 7(a) and (b) are structural views of a powerless wheel in an  
example of a mobile robot embodying the present invention;

25 Figure 8 is a vector view showing a method calculating the shortest return distance of a robot at the respective moved point of the mobile robot by a triangulation method; and

Figure 9 is a flowchart showing an example of an operating sequence in use of the present invention.

In Figures 2 and 3, numerical reference number 1 denotes a body of the mobile robot. An inertial navigation system 2 precisely controls the moving angle of the robot, recognizes the directional angle to be deviated during the motion of the robot toward a predetermined position as the relative vector at the time of an initial start, and senses the motion of the robot to compensate the angle deviated due to obstacles and the like on a surface of the moving path at all times. A driving means 3 is a driving device which allows the robot 1 to be precisely turned in direction at an angle of  $90^\circ$  under the operation of a direction control motor which will be described later and allows the robot to be also advanced along the moving path. A measure means 23 is a powerless wheel which cooperates with the driving means 3 and measures the moved distance, and 50 is a microcomputer, that is, a control means for controlling the whole operation of the system, the control means being connected through wires to the navigation system 2, the driving means 3 and the powerless wheel 23 and allowing the data to be transformed therebetween.

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Figure 4 shows a structural view of the navigation system. Figure 4 (a) shows the structural relation between a first permanent magnet 5 and a magnetic coil 13, etc. and (b) shows in more detail the first permanent magnet 5 on a cylindrical plate 4. As seen from the drawings, on the cylindrical plate 4 is mounted the first permanent magnet 5 having an N-pole and an S-pole at its respective ends to thereby form a compass 6. On the upper side of the compass 6 is mounted a first light generating device 7 for generating light and

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a first optical sensor 8 for sensing reflected light which has been emitted towards and reflected back from the first light generating device 7.

5 In addition, when a frictional force is produced between the compass 6 and the bottom of the navigation system 2 because of the self-weight of the compass 6, the force acts as an obstructive cause which disturbs the compass from indicating accurately the moved position of the robot.

To remove such a cause, a second permanent magnet 11 is mounted on  
10 the bottom of the compass 6, the second permanent magnet having ends which are polarized respectively into an N-pole and an S-pole. Also, a magnetic coil 12 is mounted below the second permanent magnet 11, the magnetic coil 12 having the same polarity as the second permanent magnet 11.

15 With this structure, if the magnetic coil 12 is magnetized as the power supply voltage is supplied and the robot is operated, the second permanent magnet 11 having the same polarity as that of the coil 12 will be pushed up by repulsion of the same polarity, so that the whole of compass 6 is supported by the supporting shaft 13, which is located in the air above a fixed position  
20 by the magnetic force. This allows accurate indication of the moving direction of the robot. Moreover, a cylindrical reflecting plate 10 is provided on the cylindrical periphery of the compass 6 so that, while the compass can indicate a fixed direction regardless of the movement of the robot, the plate 10 is moved at an angle that corresponds to a flow angle according to the  
25 movement of the robot 1. Accordingly, if light is emitted from the light generating device 7 disposed on the compass 6, various waveforms in the reflected light are sensed by the first optical sensor 8. That is, various waveforms in the reflected light sensed as described above are analyzed by the

microcomputer 50 to determine whether or not the robot is correctly moved on the moving path.

Figure 5 is an exemplary view illustrating the rotative direction and the measurement of angle in the navigation system. Figure 5 (a) shows the reflecting mirror 9 fixedly arranged in the cylindrical reflecting plate 10 shown in Figure 4 so as to allow the microcomputer to determine a rotation angle to the right or the left with directivity, (b) shows the right and the left directivity of the reflecting mirror 9 fixedly arranged on the cylindrical reflecting plate 10. (c) shows the waveform sensed by the first optical sensor 8 when the robot is rotated in the direction B of Figure 5-(b), and (d) shows the waveform sensed by the first optical 1 sensor 8 when the robot is rotated in the direction A of Figure 5 (b).

More particularly, when the light-reflecting plate 10 rotates, then the reflecting mirror 9 with directivity will be rotated to the left or the right - that is, the reflecting mirror 9 is rotated in the direction A or B as shown in Figure 5 (b), the shape and the amount of the waveforms reflected from the reflecting mirror 9 are different from each other. In other words, the waveform sensed by the first optical sensor 8. when the robot is rotated in the direction B as shown in Figure 5 (c). is different from the waveform sensed by the optical sensor 8 when the robot is rotated in the direction A as shown in Figure 5 (d).

Accordingly, the microcomputer 50 can read the different waveforms and determine the rotated angle and the rotational direction of the robot to the left or to the right.

Figures 6 (a) and (b) show a structural view of a driving device which may form part of the mobile robot of Figures 2 to 5. A driving wheel 15 is mounted on a cylindrical plate 14 so that the robot 1 may be moved in proportion to a rotation number of a driving motor 17 connected through a plurality of gears 16 to the central axis P of the driving wheel 15 and a plurality of gears 18 formed on the periphery of the cylindrical plate mesh with gears 18-1 connected to a direction control motor 19.

With this structure, in the case that cylindrical plate 14 is correctly turned by an angle by  $90^\circ$  according to the action of the direction control motor 19, the magnet 20 disposed on the top of the cylindrical plate 14 may coincide with magnet sensing sensor 22 on the cylindrical plate support 21, then a change of direction of the robot will be completed and the action of the direction control motor 17 will be stopped. If so, the microcomputer drives again the driving motor 17 to thereby allow the robot to be moved by a constant distance. If the robot 1 is rotated due to an obstacle, the navigation system 2 senses the moved angle and the microcomputer 50 determines the moved angle and compensates that angle to precisely move the robot.

Figures 7 (a) and (b) are structural views showing an example of a powerless wheel 23 which may be used in the mobile robot described above. The robot is provided with a cylindrical driving plate 26 on which a plurality of holes 25 are formed at regular intervals along the circumference, and aligned with a central axis 24 of the powerless wheel 23. At opposite sides of the holes 25 are disposed a second light generating device 27 for generating a light and a second optical sensor 28 for sensing the light which is emitted from the second light generator 27 and is transmitted as shown in Figure 7 (b). With this structure, the numbers of waveform passed through the holes

25 which are formed at one end of the central axis 24 are sensed by the second optical sensor 28 and then the sensed data is entered into the microcomputer 50 while the powerless wheel 23 is operated according to the movement of the robot 1 (that is, according to the action of the driving device). The microcomputer 50 correctly determines the moved distance of the robot 1 on the basis of the sensed data by using a previously-entered moving distance determinable program.

Figure 8 is a vector diagram showing a method for calculating the shortest return distance by triangulation at a present position of the robot.

The robot 1 with inertia compass starts from the start point and moves toward a desired position. In that case, if the robot is deviated from its normal path due to an obstacle on the moving path, the microcomputer 50 compensates always the moved angle by using the sensed data in the navigation system 2 to allow the robot to be correctly moved along the normal path and the microcomputer 50 receives the reflected light sensed by the second optical sensor 28 disposed on the powerless wheel 23. As a result, when the microcomputer 50 determines that the robot has arrived at a point A' coincident with data relative to a predetermined move distance x previously entered, the robot 50 is turned at an angle of  $90^\circ$  to the right or to the left by controlling of the microcomputer 50. Herein, if the cylindrical plate 14 is accurately rotated by  $90^\circ$ , in accordance with the operation of the direction control motor 19 in the driving device 23, the turn in the right-angled direction will be completed at a moment that the magnet 20 disposed on the top of the cylindrical plated 14 coincides with the magnetic sensor 22 on the cylindrical plate support 21. After the robot has been correctly turned by  $90^\circ$  the microcomputer 50 receives again data relative to the reflected light sensed

by the optical sensor 28 in the same manner as described above and controls the robot to be moved by a predetermined distance  $y$ . When the robot 1 reaches the point A, the microcomputer 50 determines the rotation value of the cylindrical reflecting plate 10 arranged in the navigation system 2 and computes the distance  $X$  to the point A', and in the distance  $Y$  to the point A, and the shortest return distance with the angle  $\alpha_1$ , by a triangulation method. The shortest return distance is shown as  $1'$  in Figure 8.

Thereafter, if the robot 1 turns in direction at the point A and then moves by the distance  $y'$  toward the point B, the microcomputer 50 calculates the shortest return distance  $2'$  with the angle  $\alpha_2$ . If the robot 1 is moved by the distance  $X'$  to reach to the point C, the microcomputer 50 calculates the shortest return distance  $3'$  by using the angle  $\alpha_3$  and stores the distance  $3'$ . As a result, the robot may be quickly returned to its original start point by controlling of the microcomputer 50 based on the distance  $3'$ .

Figure 9 is a flowchart showing an example of an operating sequence of the robot 1. First, a power voltage is supplied to the robot 1 with an inertia navigation system. The microcomputer 50 then sets an initial value on the basis of an initialize program at step S1 and then the microcomputer 50 drives the driving device 3, the navigation system 2 and the powerless wheel 23 at step S2. Accordingly, the driving device 3 drives the robot 1 to be moved in proportion to the rotation number of the driving motor 17 and the navigation system 2 checks whether the robot 1 is moved at the precise moving angle.

Consequently, the procedure is advanced to step S3 and at this step S3 the first light generator 7, which is located on the compass 6 in the inertia

navigation system 2 inertia and operated by the microcomputer 50 at step 2, emits a light toward the advance direction of the robot so that the light is reflected from the reflecting mirror 9, and the second light generating device 27 in the powerless wheel 23 emits also a light. In practice, the steps S2 and S3 are performed simultaneously.

Next, the procedure is advanced to step S4 and at this step S4 the first and second light sensors 8 and 28 sense their respective reflected and transmitted lights. Continuously, the numbers of waveform and the shape informations of the light sensed by the first and second optical sensors 8 and 28 are entered into the microcomputer 50 at step S5. The procedures described above are performed repeatedly and the procedure is advanced to step S6. At this step S6, if the angle of motion of the robot 1 is deviated by presence of an obstacle that impedes the advance movement of the robot 1 (i.e. "yes"), the microcomputer 50 determines the erroneous movement of the robot 1 because the numbers of waveform and the shape of the reflected light sensed by the first and second optical sensors 8 and 28 respectively disposed in the navigation system 2 and the powerless wheel 23 differ with the data previously stored in the microcomputer 50, whereby the microcomputer 50 compensates the moved angle at step S7.

The procedure is then advanced to step S8 and the robot is moved straight by a predetermined distance previously entered in the microcomputer 50 and at step S9 the microcomputer 50 determines whether or not the number of waveform and the shape of the reflected light sensed by the second optical sensor 28 in the powerless wheel 23 coincide with data in a predetermined moving distance program previously entered therein. If both data coincide with each other, the microcomputer 50 determines that the robot

has been moved by a predetermined distance and controls the robot 1 to be turned by 90° to the right or the left.

5 This turn is performed by the direction control motor 19 in the driving device 3 and is completed if the magnet 20 on the top of the cylindrical plate 14 coincides with the magnet sensor 22 on the cylindrical plate support 21. Thereafter, the procedure is returned to step S6 and at step S6 if data related to the reflected light differ with data entered in the microcomputer 50 due to the presence of an obstacle, the microcomputer 50 compensates the moving  
10 angle in the same manner described above thereby to move straight the robot 1 straight at step S8 and then turns by 90° the robot 1 to the right or the left. Next, at step S10, the microcomputer 50 receives the rotation value of the cylindrical reflecting plate 10 in the navigation system in accordance with the turn of the robot 1, determines whether or not the operation is precisely  
15 performed and then measures the moving vector by using the triangulation method to calculate the shortest return distance at step S11. Accordingly, the robot 1 may be returned to the started point along the calculated shortest return distance at step S12.

20 On the other hand, at step S6 if no obstacle is detected on the moving path, the procedure is directly advanced to step S8 to perform operations after step S8.

25 It is to be understood that the invention is not limited to the above embodiments, and various changes and modifications may be effected therein by one skilled in the art without departing from the scope of the invention as defined in the appended claims.

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For example, a modified robot may be arranged to turn in angles of other than  $90^\circ$ .



**CLAIMS**

1. A mobile robot comprising:

5           inertial navigation means for providing information indicating a moved angle between an initial start position of said robot and a current position, the information being used to plot a relative vector between said current and initial start positions, the inertial navigation means being further arranged to enable re-plotting of the vector following deviation of the robot due to the  
10   robot encountering an obstacle or the like in the course of its movement by providing new compensating information representing the moved angle;

          means for measuring a moved distance of the robot;

15           directional turning means for turning the robot by a predetermined amount upon encountering an obstacle or upon the robot having moved by a predetermined distance; and

          control means for controlling the directional turning means,  
20   determining moved angle on the basis of the information from the inertial navigation means, and calculating a shortest return distance for the robot to be returned to the initial start position.

2. A mobile robot according to claim 1, wherein said inertial navigation  
25   means comprises a first light generating device, a first optical sensor, a compass and a cylindrical reflecting plate, the first light generating device and the first optical sensor being formed on the compass so as to rotate therewith relative to the cylindrical reflecting plate in accordance with the moved angle



of the robot such that light emitted from the first light generating device and reflected by said reflecting plate is sensed by the first optical sensor and information therefrom representing the moved angle is provided to the control means.

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3. A mobile robot according to claim 1 or 2, wherein said means for measuring a moved distance comprises a powerless wheel, a second light generating device and a second optical sensor, the powerless wheel being arranged to rotate with respect to said second light generating device and  
10 second light sensor about a central axis thereof. the powerless wheel having a plurality of radially spaced apart holes forme therein and the second optical sensor and second light generating device being arranged to be mounted on either side of the wheel such that as the wheel turns, light emitted from the second light generating device is able to pass through said holes and be  
15 detected by the second optical sensor, moved distance of the robot being measured on the basis of wave form pulses produced by the second optical sensor as light passes through the holes.

4. A mobile robot according to claim 1. 2 or 3 wherein said control  
20 means comprises a magnet, a cylindrical plate and a magnet sensing sensor, the magnet and magnet sensing sensors being arranged for relative rotation in correspondence with turning motion of the robot, the control means determining the completion of a 90 degree turn at a moment when the magnet sensing sensor detects the presence of the magnet.

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5. A mobile robot according to claim 1. 2. 3 or 4, wherein said control means calculates the shortest return distance by using a triangulation method



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based on the initial start position and an actual point on the course of movement of the robot.

6. A mobile robot substantially as hereinbefore described with reference  
5 to figures 2 to 9 of the accompanying drawings.