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Mobile Robot with Preliminary-Announcement Function of Forthcoming Motion using Light-ray

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***Abstract*— This paper discusses the design and the basic characteristic of the mobile robot PMR-1 with the preliminary-announcement and display function of the forthcoming operation (the direction of motion and the speed of motion) to the people around the robot by drawing a scheduled course on a running surface using light-ray. The laser pointer is used as a light source and the light from the laser pointer is reflected in a mirror. The light-ray is projected on a running surface and a scheduled course is drawn by rotating the reflector around the pan and the tilt axes. The preliminary-announcement and display unit of the developed mobile robot can indicate the operation until 3-second-later preliminarily, so the robot moves drawing the scheduled course from the present to 3-second-later. The experiment on coordination between the preliminary-announcement and the movement has been carried out, and we confirmed the correspondence of the announced course with the robot trajectory both in the case that the movement path is given beforehand and in the case that the robot is operated with manual input from a joystick in real-time. So we have validated the coordination algorithm between the preliminary-announcement and the real movement.**

I. Introduction

This paper discusses the design and the basic characteristic of the mobile robot PMR-1 (**Fig. 1**) with the preliminary-announcement and display function of the forthcoming operation (the direction of motion and the speed of motion) to the people around the robot by drawing a scheduled course on a running surface using light-ray.

In recent years as the birthrate is decreasing and the society is aging, the application and utilization of the robotic and mechatronic technologies are expected not only for elderly or disabled people but also for ordinary people in daily life. So the human-coexistence type robot which operates in the same living space and the working space as people do are increasing in number. Such human-coexistence type robot has to avoid the contact and collision with people. However since the robot is an artificial existence, it is difficult for people to guess the forthcoming operation of a robot if it doesn't equip some special function. Then there have been various researches on safety, for example, the suspension function if someone approaches a robot [1], [2], [3], [4], the flexible cover which makes people not to feel pain even in contact [5], [6], the method to make the robot's joint soft and flexible using hardware [7] or software [8] technique, and so on.

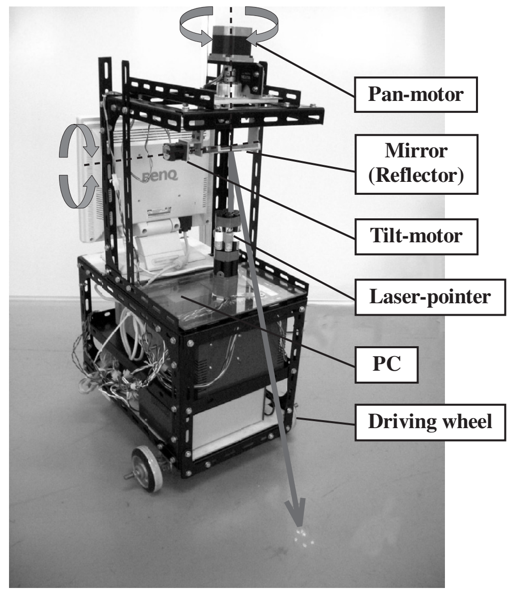

Fig. 1. Overview of PMR-1R3

We consider the preliminary-announcement and display function to show the people around the robot the robot's forthcoming operation before it moves. This research aims at proposing a new simple and intelligible way to preliminary-announce and indicate both the direction of motion and the speed of motion of the mobile robot which runs on a 2-dimensional plane.

II. Preliminary-announcement and display of mobile robot's forthcoming operation

A. Conventional method

Conventional mobile machine only tells its approach. The automatic vehicle which conveys goods in a factory and the conveyance robot which carries meal or chart in a hospital only blinks or rotates a warning light or plays some melody from a loudspeaker. Some heavy vehicles, such as motortrack and autobus, tells "turning left" from a loudspeaker towards the circumference to prevent the involvement accident when it makes left turn at crossings. In this case the means to communicate information is carried on the mobile object.

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When a train approaches a station, an indicator will light on and an audio assist will be announced on the platform. In the case that the motion trajectory is decided beforehand like a train, the means to communicate information can be installed in the environment. In either case the conventional mobile machine only informs inexact information about operation such as a left turn or an approach to unspecified people around the machine. It only expects people to go away from the motion trajectory, and the contents of information are simple but inadequate to understand the detailed operation of the machine.

On the other hand among human beings, for example, in the case to care and support elderly person it is said that the care giver should act telling the care reciever the next operation to do in detail. This eliminate the uneasy and anxious feeling of the care reciever and make him/her prepare for the forthcoming operation psycologically and physiologically. Sound or voice is useful to transmit information to all the people around, but information tends to be transmitted compulsorily also to those who do not wish. So we consider the method to communicate other than sound or voice in this research.

B. Related work

In transferring the intention among human beings, Gesture Cam [9], Gesture Laser [10], Gesture Man [11], Shoulder-Worn Active Camera/Laser [12], etc. were proposed as a system which supports to transfer the supervisor's intention to the operator in a remote site in order to give instructions.

Most conventional researches on the nonverbal interface between a person and a machine are in the direction from a person to a machine. There are many researches on the image processing of human gestures [13], [14], [15], [16], and the face and sight line [17], [18], [19], [20], [21] to gauge human action and intension both to communicate with a machine and to operate some apparatus [22]. On the contrary there are few researches in the direction from a machine to a person. As the internal condition of a robot, the residual quantity of battery, the internal temperature, etc. were displayed on a monitor screen of a mobile robot by way of experiment [23]. As the expression of a robot's forthcoming operation, the projection function in a shared space between a person and a robot was proposed [24]. And the experiment of an industrial robot which equipped two or more Light Emitting Diodes at the tip aiming at support on eating for disabled people was also reported [25], [26].

C. Method to preliminary-announce and display the forthcoming operation using light-ray

The characteristic or capability of each robot is so various in individuals that people cannot summarize as some common sense. Therefore the function to preliminary-announce and display the forthcoming operation is necessary when a robot is working in a human-coexisting environment. The preliminary-announcement and display function of robot's forthcoming operation will be important for the people around the robot regardless as to whether the robot operates autonomously or it is controlled remotely, even if the robot is a human-coexistence type. Although not only the same method as human being but a newly-developed means may be used to transmit some information from a robot to a person, it must be easy for people to suppose and understand and it must be able to be judged from the common sense which ordinary people has. Moreover the kinds of information transmitted simultaneously should be as fewer as possible in order to suppress the amount of information which a person has to process. Here we aim at the mobile robot which moves around on a 2-dimensional plane, so we think that the direction of motion and the speed of motion are important as the information on the operation. We have examined the methods to indicate the information and have proposed two types ((1) the state at some future point is preliminary-announced and displayed, and (2) the present and future motion is preliminary-announced and displayed continuously), and four methods ((a) lamp, (b) blowout (telescopic and flexible arrow), (c) light-ray, and (d) projection) [27]. The former two, (a) and (b), are in type (1), and the latter two, (c) and (d), are in type (2). Computer simulation has been used to evaluate and examine its effect, validity, and timing to announce [28].

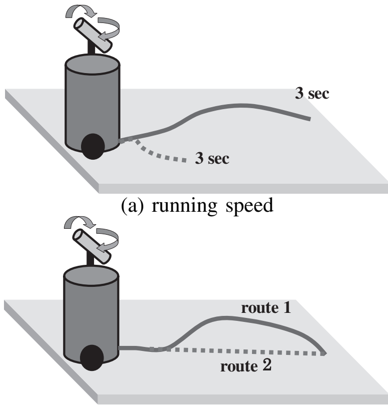
This paper discusses the design and the basic characteristic of the mobile robot PMR-1 which draws a scheduled course on a running surface using light-ray. The period to display the scheduled course beforehand is fixed and the course is expressed with the afterimage of the light-ray projected on a running surface. The drawn course directly shows the direction of motion, and the speed of motion can be announced as the length of the course (**Fig. 2**(a)). The strong feature of this method is it can display the intermediate state during going to some point, for example, whether the robot goes straight or it goes via some other point (**Fig. 2**(b)). The method can be expected not only to apply to robotic systems but also to develop new equipment which can be carried on four-wheeled or two-wheeled vehicles instead of the present direction indicator (winker). Toyota Motor Corp. has announced the "road surface depiction (laser tactile sense)" in autumn 2004 [29], but this mainly aims at the collision avoidance among loaded vehicles. Indication of the next motion of vehicle to pedestrians who are near the vehicle is seldom taken into consideration.

III. Preliminary-announcement and display unit of PMR-1

A. Structure of preliminary-announcement and display unit

The laser pointer is used as a light source and the light from the laser pointer is reflected in a mirror (**Fig. 3**). The light-ray is projected on a running surface and a scheduled course is drawn by rotating the reflector around the pan and tilt axes. Reciprocating rotation of the reflector can reduce the required torque of driving motor comparing with swinging the laser pointers directly and it will make the whole of the mechanism lightweight rather. The fixed light source is easy to contrive such as changing light quantity.

Laser pointer is one of the "pocket laser application devices" as a regulated product with the consumer products safety law



(a) running speed

(b) intermediate course

Fig. 2. Features of drawing a course

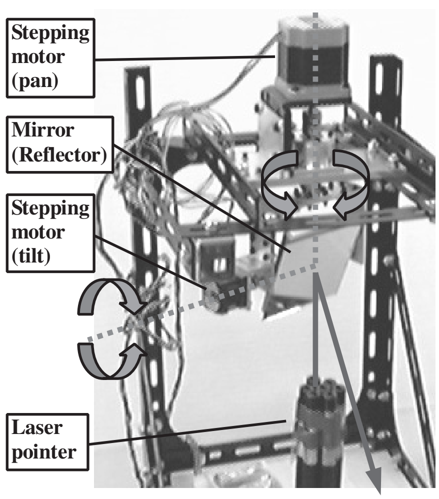


Fig. 3. Overview of preliminary-announcement and display unit

[30]. So the private laser pointer is strictly required to be in the safety class under class-2 (it is usually safe owing to low output and an eye is protected by dislike reactions such as a blink) in JIS C 6802 [31]. Here we used a commercial product (LPP1-635-1S made by FM Laser Tec. Co.) with the red semiconductor laser of the wavelength of 635[nm] under the output power of 1[mW]. We thought it is required to increase the amount of light in order to make the light spot on a running surface legible as much as possible, even though it depends on the conditions of a road surface or environment. So we used seven laser pointers which are bundled and set along the vertical axis facing up just under the reflector. We can also use them, for example, to improve the indication about the mobile speed of the robot with controlling the number of light to turn on according to the length of the scheduled course.

The rotation axis around pan direction is vertical and the rotation axis of tilt direction is horizontal to change the direction of the reflector. These two axes are arranged as crossing at a point, and the mirror is set so that the center of the reflective surface may correspond with the point as much as possible. Calculation of the projection position of light-ray on a running surface is simplified with corresponding the

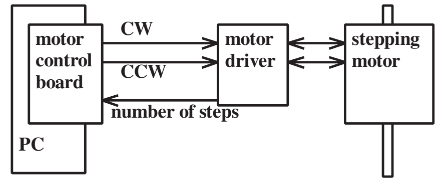


Fig. 4. Control architecture of driving mechanism of announcement unit

direction of the optical axis of laser pointer (vertical axis) with the pan axis to rotate the mirror (details will be mentioned later). Range of rotation both around the pan axis and around the tilt axis is set up so that the course from the present to 3-second-later could be projected even if the robot moves at the speed of 200[mm/s]. Especially on a measure for safety the mechanical stopper is set to limit the upper angle around tilt axis of the reflector so that the laser light may not irradiate upward from the height of the installed reflector.

The stepping motors are used to rotate the reflector around the pan and the tilt axes in the driving mechanism The stepping motor is better than the small-sized DC motor with reduction gears considering the balance among speed, torque, and self-weight for the driving mechanism. The position control with high precision can be achieved even without the complicated driving circuit and the angle-detector like potentiometer. Absence of reduction gear and potentiometer makes the inertia moment small and let the whole unit small and lightweight. The stepping motors are selected from the minimum required torque (0.26[Nm] for the pan axis and 1.5×10^{-3}[Nm] for the tilt axis) to drive the reflector, 90[mm] square and 300[g], and the supporting mechanism in 2[Hz] (**Table I**). The output axis of the stepping motor is connected to the rotation axis of the reflector through a mechanical coupler in order to compensate the mechanical error and to make the disturbing force in unnecessary direction small as much as possible. The reflector and the tilt motor are hung from the upper board along the rotation axis of the pan motor. Both the load by the self-weight of the structure and the load by the disproportionate moment are supported with two deep-groved ball bearings on the upper board, so that unnecessary load doesn't apply to the shaft of the pan motor directly. Reciprocating rotation of the reflector should be quick as much as possible if the projected light spot on a running surface looks bright enough. However the visibility of the light spot will become worse when the not-bright light spot is moved quickly. So the cycle of reciprocating rotation of the reflector is set to 2[Hz] in maximum considering the experimental conditions. Motor drivers which drive the stepping motors are connected with the controller board (PCI-7211A made by Interface Co., 2ch) which is inserted in PC controller, and the position of the motors is controlled with the CW or CCW pulse signals to the motor drivers from PC (**Fig. 4**).

B. Control of preliminary-announcement and display unit

In order to draw the mobile robot's scheduled course on a running surface using light-ray, the rotation angle of the

TABLE I

SPECIFICATIONS OF DRIVING MECHANISM OF ANNOUNCEMENT UNIT

Item	Specification
Size [mm]	D80 × W170 × H260
Weight [kg]	1.8
Pan Torque [Nm]	0.83
Range [deg]	-90 ∼ +90
Speed [deg/s]	Max. 240
Resolution [deg]	0.72
Tilt Torque [Nm]	0.033
Range [deg]	0 ∼ +45
Speed [deg/s]	Max. 240
Resolution [deg]	0.72

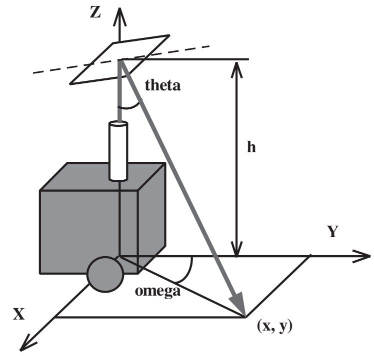


Fig. 5. Light-ray projection

reflector is controlled so that the light spot must be projected correctly to the forthcoming position of the robot. The robot coordinate system is set up (**Fig. 5**) in which the coordinate origin is at the intersection of the running surface (horizontal plane) and the vertical axis which corresponds both with the optical axis of the laser pointer and with the rotation axis of the pan direction. The relation between (x, y) and (ω,θ) is simply expressed as the following equations using trigonometric functions, where h[m] is the height from the running surface to reflective surface, (x, y)[$\angle$m] is the coordinates position to project the light-ray, ω[rad] is the angle between Y-axis and the line which connects the coordinate origin and the coordinate position to project, and θ[rad] is the reflection angle.

$$\omega = tan^{-1}(x/y) \tag{1}$$

$$\theta = tan^{-1}\sqrt{(x^2 + y^2)/h^2} \tag{2}$$

Moreover, if α[rad] is the rotation angle around the pan axis of the driving mechanism and β[rad] is the rotation angle around the tilt axis, α is equal to ω and β becomes half of θ based on the reflection law in optics (incidence angle = reflection angle).

$$\omega = \alpha \tag{3}$$

$$\theta = 2\beta \tag{4}$$

Therefore, the rotation angle (α, β) of the reflector is expressed as the following equations from the projection position (x, y) of the light-ray.

$$\alpha = tan^{-1}(x/y) \tag{5}$$

$$\beta = \frac{1}{2}tan^{-1}\sqrt{(x^2 + y^2)/h^2} \tag{6}$$

The mobile robot's scheduled course is drawn by repeating the reciprocating operation of the reflector, positioning the light-ray one after another from the initial position (light-ray is projected just downward of the robot at first) to the coordinates position of the robot at 1-second-later, 2-second-later, and 3-second-later, and returning to the initial position after projecting the robot's position at 2-second-later and 1-second-later. It is necessary just to control each stepping motor using the equations (5) and (6) to do that.

However, the error between the course drawn with light-ray and the robot's actual path and the round trip error on drawing with light spot will become large, when the robot moves and the speed of robot becomes relatively high comparing with the speed of the reciprocating operation of the reflector, if the rotation angle of the reflector which is calculated from the position of the robot at 1-second-later, 2-second-later, and 3-second-later is computed only at the beginning of the operation of the reflector and those angles are controlled one by one, since the cycle of the reciprocating rotation is set to 2[Hz] considering the visibility that is explained in Section III-A. Then we decide to compute the following target rotation angle of the reflector considering the movement of the robot during the period to achieve the target angle whenever it is realized (**Fig. 6**). For example, at the time the rotation angle (ω_1, θ_1) of the reflector for the robot's position at 1-second-later (x_1, y_1) is realized, the target rotation angle (ω'_2, θ'_2) of the reflector is calculated after computing the relative position (x'_2, y'_2) of the robot at 2-second-later considering the movement of the robot during the period to realize the angle (ω_1, θ_1) of the reflector.

C. Projection experiment of light spot

The projected position of the laser light is measured on the running surface and it is compared with the target position in order to check whether the developed preliminary-announcement and display unit can project the light spot to the exact position correctly. The experiment is carried out under the condition that the announcement unit is equipped on the movement unit to be built as a robot which will be explained in Section IV-A. The height h from the running surface to the reflective surface is 690[mm]. The target position on the running surface in the robot coordinate system is from -550 to 550[mm] at every 50[mm] along the longitudinal axis X and from 300 to 700[mm] at every 100[mm] along the anteroposterior axis Y. Allowable error is set as the displacement when the stepping motor moves both around the pan axis and the tilt axis with one forward or backward input pulse respectively. The result of the actual measurement and the allowable error is shown in **Fig. 7**. The point near each target position to project is the actual measurement and the pseudo-quadrangular around each target position is the allowable range. Those are illustrated expanding by 5 times from each target position along the fore/back direction and the right/left direction. As

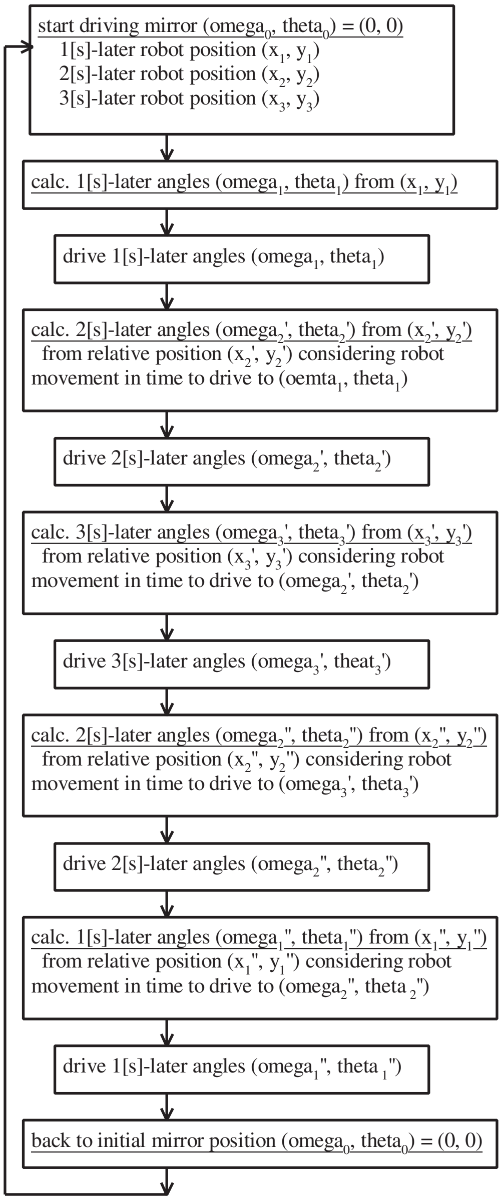


Fig. 6. Procedure of drawing a course

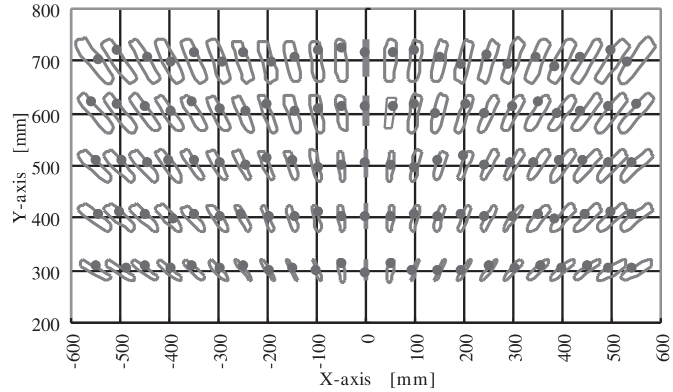


Fig. 7. Results of projection experiment

TABLE II
SPECIFICATIONS OF PMR-1R3

Item	Specification
Size [mm]	D460 × W480 × H910
Weight [kg]	30
Max. speed (trans.) [mm/s]	180
Max. speed (rotat.) [deg/s]	20

we explained in Section III-A there remains a gap between the point where two rotational axes cross and the point where the light-ray reflects on the mirror, and the gap influences the accuracy of projection. However it has checked that all actual measurements are in the allowable range and the developed preliminary-announcement and display unit could project the light-ray to the target position almost correctly.

IV. Coordination between Preliminary-Announcement and Movement

A. Structure of PMR-1

The specification of the developed mobile robot is shown in **Table II** and the system configuration is illustrated in **Fig. 8**. The system consists of the mobile unit and the preliminary-announcement and display unit. The controller PC is also equipped and the power source (AC100[V]) is only provided from outside. The mobile unit is a two-driving-wheel type and two driving wheels on both sides are driven by DC servo motor with reduction gear. Two ball-casters are used as followers. The preliminary-announcement and display unit is equipped on the mobile unit. It is more desirable to install the reflector at high position in order to draw a scheduled course on a running surface for a long distance from the robot correctly as much as possible. However the announcement unit is installed lower and the height from the running surface to the reflector is set to 690[mm] so that it might be free from the possibility that laser light goes into the eyes of the people around the robot. Consequently the total height of the robot including protruding portions is 910[mm] and this is lower than Japanese kindergartener's average height. So the reflector is positioned lower than most of the kindergartener's eyes.

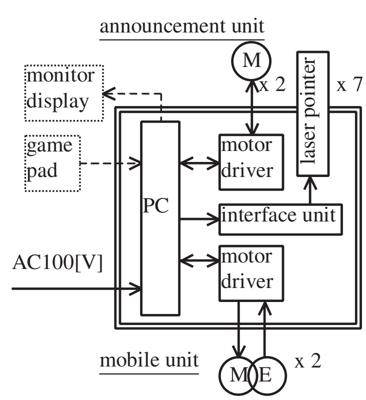


Fig. 8. System configuration

B. Coordination between preliminary-announcement and movement

The preliminary-announcement and display unit of the developed mobile robot can indicate the operation until 3-second-later, so the robot moves drawing the scheduled course from the present to 3-second-later. The relation among the instruction input, the preliminary-announcement, and the movement control as time goes on is illustrated in **Fig. 9**. The execution of the instruction will delay for 3 seconds after the instruction is inputted, while the robot announces the operation beforehand from the present to 3-second-later.

The robot takes a speed command in every 50[ms] regardless as to whether it moves along the course decided beforehand or it receives the instructions in real-time from some input equipment like joystick. The speed commands during the recent 3-second period are always accumulated in the command buffer, and the command value at 3 seconds ago is always used as the target value to control the mobile robot's driving wheels. The control cycle for the angle position of the mobile robot's driving wheels is also every 50[ms].

The preliminary-announcement and display unit receives the target coordinates position of the robot for 1-second-later, 2-second-later, and 3-second-later from that time at the beginning of the reciprocating motion of the reflector. Then it draws the scheduled course on a running surface using the procedure explained in Section III-B. As explained in Section III-B, the present coordinates position of the robot at that time is referred to every time it calculates the next target angle of the reflector after it realizes the old target angle. After the reflector goes back to the initial position and one reciprocating operation is completed, the annoucement unit receives again the target coordinates position of the robot at 1-second-later, 2-second-later, and 3-second-later from that time, then the next reciprocating operation starts to draw a scheduled course. The reciprocating operation is carried out in about 500[ms].

C. Experiment on coordination between preliminary-announcement and movement

In order to check the correspondence of the scheduled course drawn using the light-ray to the mobile robot's actual trajectory, the experiment on the coordination between the preliminary-announcement and the movement is carried out. It is performed both in the case that the course is given beforehand and in the case that the robot is operated with the manual input in real-time from a joystick. In the case of the pre-decided course the time sequence of the speed command value is prepared beforehand and it is given to the robot.

1) Experiment on course given beforehand: To check whether the preliminary-announced course and the robot trajectory are corresponding the robot moves on a course including going straight, clockwise turning, and counterclockwise turning and the robot changes its speed of motion. **Fig. 10(a)** shows an example of the experimental result in which the actual robot trajectory (square) and the scheduled course drawn with light-ray (circle) are given in the world coordinate in which the coordinate origin is the robot's initial position. From

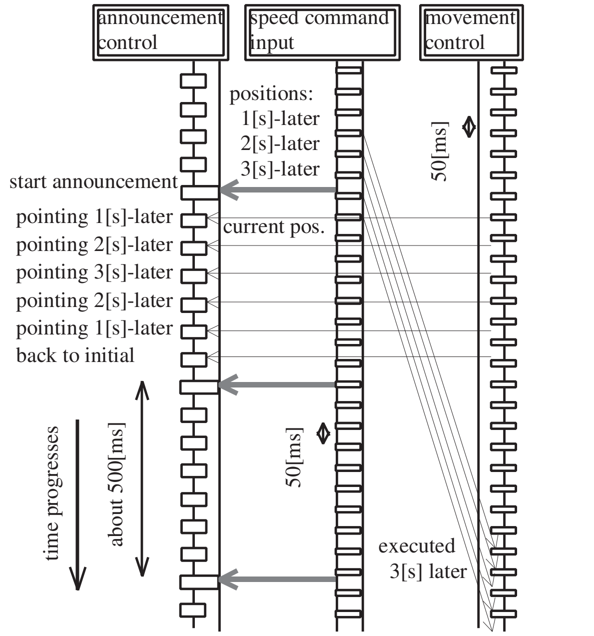


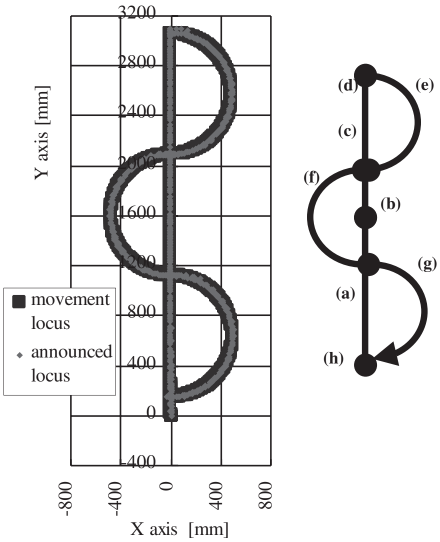
Fig. 9. Coordinatoin between preliminary-announcement and real movement

the static condition the robot (a) goes straight on at 140[mm/s] for 3[s], at 200[mm/s] for 3[s], at 140[mm/s] for 4[s], and it (b) stops. Then it (c) goes straight on in the same manner once again, and it (d) stops. It turns to the right for 90[deg] on the spot to change its direction. Then the robot does (e) clockwise turning for 12[s], (f) counterclockwise turning for 12[s], and (g) clockwise turning for 12[s] again, all at about 127[mm/s] along the circle with 970[mm] in diameter, until (h) coming back to the initial position. From **Fig. 10(a)** we can confirm the correspondence of the announced course to the robot trajectory when the robot moves on a course including going straight, clockwise turning, and counterclockwise turning with changing its speed.

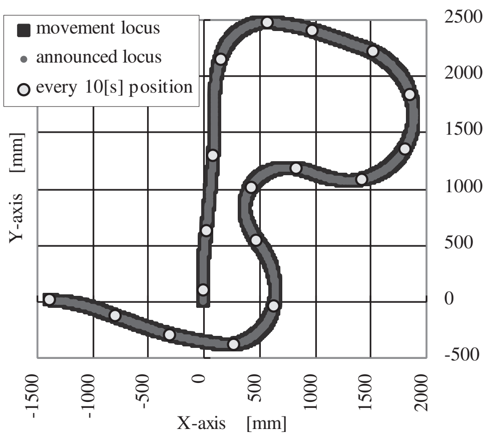
2) Experiment in real-time operation: To check whether the announced course and the robot trajectory are corresponding employing the algorithm explained in Section IV-B, the robot is operated in real-time with the manual input from a joystick. **Fig. 10(b)** shows an example of the experimental result in which the actual robot trajectory (square) and the scheduled course drawn with light-ray (circle) are given in the world coordinate in which the coordinate origin is the robot's initial position. In addition to indicate the robot's speed during the operation roughly, the position of the robot in every 10[s] (circle bordered in line) is shown in the figure. From **Fig. 10(b)** we can confirm that the announced course and the robot trajectory are well in agreement also in real-time operation. So we have validated the coordinate algorithm between the preliminary-announcement and the movement.

V. Questionnaire evaluation

The developed robot was exhibited to show at the RT (robot technology) cooperation plaza (organized by Japan Robot Association and Nikkan Kogyo Shimbun Ltd. held at Tokyo



(a) course given beforehand



(b) real-time operation

Fig. 10. Experimental result

Big Sight in Sept. 25-27, 2002) and we asked the visitors to perform the questionnaire evaluation. After explaining the background and the purpose of this research, the proposed method to announce and display, the total structure of the developed robot, etc. to the respondents, we showed them the robot moving with displaying a scheduled course as long as they like. The robot was operated in various courses regardless as to whether it is given beforehand or it is specified in real-time. **Fig. 11** shows an example of the appearance of the robot moving with drawing a scheduled course. Then we had the respondents to answer to the following two simple questions which are made easy to answer.

1) Robot expresses the direction of motion, in which it will move on from now, with the direction of the afterimage of the light-ray. This is intelligible / difficult to understand / no opinion.
2) Robot expresses the speed of motion, at which it will move on from now, with the length of the afterimage of the light-ray. This is intelligible / difficult to understand / no opinion.

TABLE III

QUESTIONNAIRE RESULT ON DIRECTION AND SPEED

Subject		Direction [%]			Speed [%]		
age	num	good	neither	bad	good	neither	bad
20∼29	12	75	25	0	66	25	8
∼39	10	35	50	20	10	50	40
∼49	5	80	20	0	80	20	0
∼59	6	83	0	16	100	0	0
∼69	2	100	0	0	50	0	50
Total	35	65	25	8	57	25	17

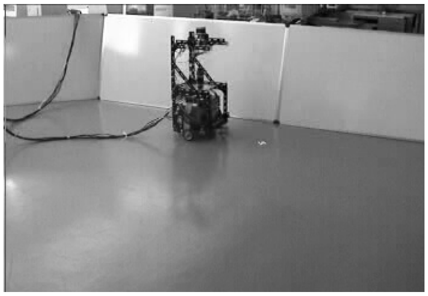
Table III shows the summary of the answers obtained from 35 respondents (31 males and 4 females). More than half answered intelligible both on the direction of motion and on the speed of motion, respectively. However we have to keep in mind that one quarter of them replied neither both on the direction of motion and on the speed of motion. Moreover a certain amount of respondents replied difficult to understand, about ten percent on the direction of motion and about twenty percent on the speed of motion. The following comments and opinions were obtained in the free entry column.

- It is better to express laser-ray not as line but as arrows.
- You should devise the method to announce the speed of motion further more.
- It should be applied also to the industrial robots.
- You have to consider perceptions other than visual sense, like auditory sensation, or the combination of visual expression with other representations.
- It will be difficult for children to understand and interpret the meaning of the descriptions.

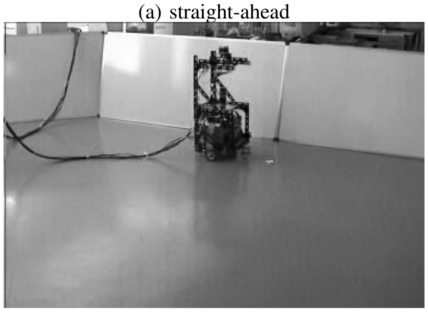
There were some opinions to desire the usage of auditory sensation. However we think the auditory sensation is the last resort since we assume the human-coexistence type robot in calm environment such as in offices or in museums. There were also opinions that it is better to change the shape of the light spot to project, so we will examine not only the change of brightness but also the change in shape of the light spot.

VI. CONCLUSION

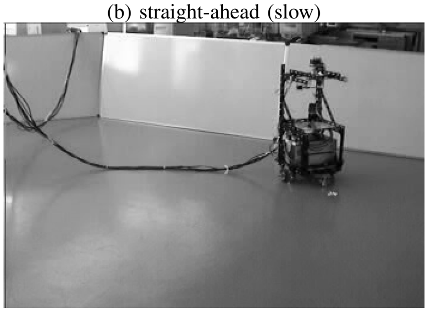
This paper discussed the design and the basic characteristic of the mobile robot PMR-1 with the preliminary-announcement and display function of the forthcoming operation (the direction of motion and the speed of motion) to the people around the robot by drawing a scheduled course on a running surface using light-ray. The laser pointer is used as a light source and the light from the laser pointer is reflected in a mirror. The light-ray is projected on a running surface and a scheduled course is drawn by rotating the reflector around the pan and the tilt axes. The preliminary-announcement and display unit of the developed mobile robot can indicate the operation until 3-second-later preliminarily, so the robot moves drawing the scheduled course from the present to 3-second-later. The experiment on coordination between the preliminary-announcement and the movement has been carried



(a) straight-ahead



(b) straight-ahead (slow)



(c) right-hand turning

Fig. 11. Movement drawing a schedule course: Light spots in figures indicate the position at about 2 seconds-later

out, and we confirmed the correspondence of the announced course with the robot trajectory both in the case that the movement path is given beforehand and in the case that the robot is operated with manual input from a joystick in real-time. So we have validated the coordination algorithm between the preliminary-announcement and the real movement. The developed robot was exhibited to show and some visitors performed the questionnaire evaluation, then more than half respondents answered intelligible both on the direction of motion and on the speed of motion, respectively.

The period of the scheduled course should be set up from the size and the performance of the robot considering intelligibility from the people around the robot, although the developed mobile robot can draw the scheduled course from the present to 3-second-later. The length of a scheduled course drawn on a running surface should have a certain amount of length in order to make the course intelligible, and the length of course depends on the mobile performance of the robot and the period to announce the robot's motion preliminarily.

Although it is satisfactory when the robot moves along a course decided beforehand, bad maneuverability will become a problem when an operator operates the robot in real-time directly with some device like a joystick only with the current coordination algorithm between the preliminary-announcement and the movement as mentioned in Section IV-B, since some fixed time delay will be always inserted in the control system. In this case it is considered that the operator's operation is predicted from his/her operating history related to the environmental conditions, the predicted operation is preliminary-announced, and the robot performs the instructions from the operator in real-time. So the future work also include the examination of the way to deal with the case that the operator operates contrary to the prediction and the case that the robot stops suddenly to secure the safety autonomously, along with the method to predict the operator's operation.

Furthermore in the questionnaire evaluation the respondents answered the questions after explained the purpose of this research, the method to announce, and so on. The method to announce should be intelligible for many people to understand and judge at a glance from the common sense as mentioned in Chapter I. So questionnaire evaluation by subject persons without prior knowledge is also included in the future work.

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