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Mobile Robot with Preliminary-announcement and Display Function of Forthcoming Motion using Projection Equipment

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Abstract— **This paper discusses the mobile robot PMR-5 with the preliminary-announcement and display function which indicates the forthcoming operations to the people near the robot by using a projector. The projector is set on a mobile robot and a 2-dimensional frame is projected on a running surface. In the frame, not only the scheduled course but also the states of operation can be clearly announced as the information about movement. We examine the presentation of the states of operation such as stop or going back including the time information of the scheduled course on the developed robot. Scheduled course is expressed as the arrows considering the intelligibility at sight. Arrow expresses the direction of motion directly and the length of arrow can announce the speed of motion. Operation until 3-second-later is indicated and three arrows classified by color for each second are connected and displayed so these might show the changing of speed during 3-second period. The sign for spot revolution and the characters for stop and going back are also displayed. We exhibited the robot and about 200 visitors did the questionnaire evaluation. The average of 5-stage evaluation is 3.9 points and 4.5 points for the direction of motion and the speed of motion respectively. So we obtained the evaluation that it is intelligible in general.**

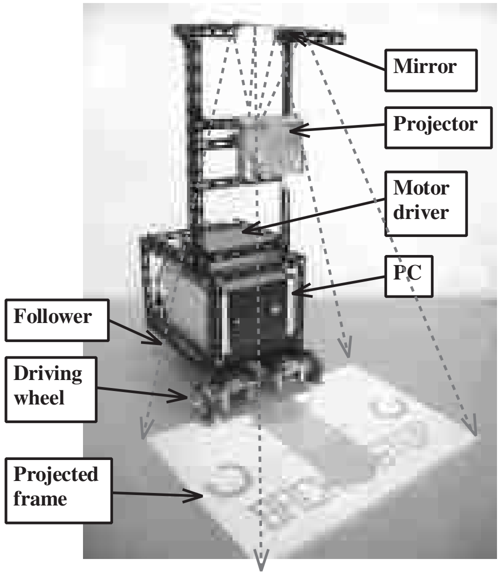

Fig. 1. Overview of PMR-5R3

I. Introduction

This paper discusses the design and the basic characteristic of the mobile robot PMR-5 (**Fig. 1**) with the preliminary-announcement and display function of the forthcoming operations to the people around the robot by using a projection equipment. It is difficult for people to judge the robot's next operation from its appearance if there is no special consideration since robot is an artificial existence. This research aims at proposing the method to preliminary-announce and indicate the speed of motion and the direction of motion of the mobile robot which moves on a 2-dimensional plane by simple and intelligible way as much as possible.

II. Method to Announce and Indicate the Forthcoming Operation by Using a Projector

We think the direction of motion and the speed of motion are important as the information about movement, since we aim at the robot which moves on a 2-dimensional plane. We 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 arrow), (c) light-ray, and (d) projection) until now [1], [2]. 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 [3], [4], [5], [6].

The main content to announce and display in type (2) is the scheduled course on a running surface. The method using light-ray (**Fig. 2**(a)) is intended only to draw the schduled course. The method using projection (**Fig. 2**(b)) develops the method using light-ray. A projector is set on a mobile robot and it projects a 2-dimensional frame on a running surface. In the frame, not only the scheduled course but also the states of operation, such as stop and going back, can be clearly announced as the information about movement. Robot's internal condition, such as the residual quantity of a battery and the warning to exhausting parts or overheating apparatus, can also be seen in the frame. If the frame to project is sufficiently-large, all that is required is just to fix the projector to the robot and a moving portion for the preliminary-announcement and display function will be unnecessary. We considere the presentation of the states of operation like stop or going back including the time information of the scheduled course on the mobile robot which we developed as a prototype. Toyota Motor Corp. has announced "road surface depiction (laser tactile sense)" as a similar system in autumn of 2004 [7], but this mainly aimed at the collision avoidance among loaded vehicles. Indicating the next motion of vehicle to pedestrians who are near the

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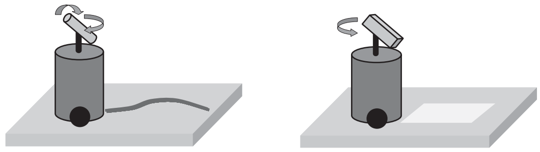


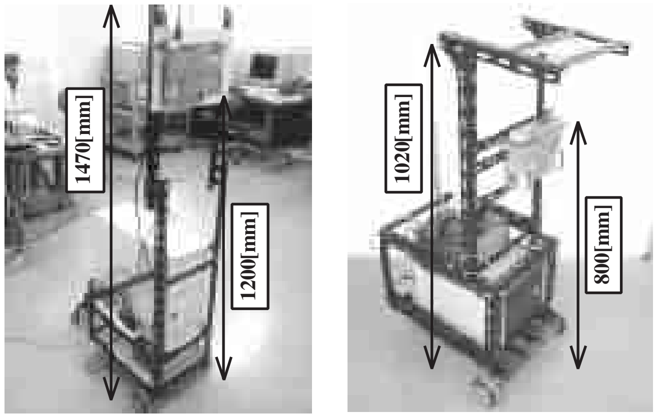
(a) light-ray (b) projection

Fig. 2. Drawing scheduled course on a running surface

TABLE I

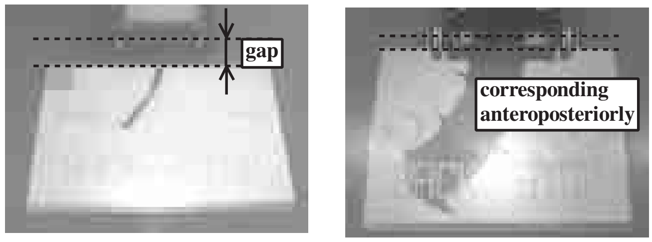
SPECIFICATIONS OF PMR-5R3

Item	Specification
Size [mm]	D500 × W440 × H1020
Weight [kg]	25.0
Max. speed (translation) [mm/s]	180.0
(rotation) [deg/s]	20.7



(a) R1 (b) R3

Fig. 3. Hight of mobile robot and position of lens of projector



(a) R1 (b) R3

Fig. 4. Position of projected frame and wheel axle

vehicle is seldom taken into consideration.

III. MOBILE ROBOT PMR-5R3

The developed mobile robot PMR-5R3 consists of the mobile mechanism and the preliminary-announcement apparatus. The specifications of PMR-5R3 are shown in **Table I**. PC for control is carried and only the power source (AC100 [V]) is supplied from the outside.

A. Hardware

Here we explain focusing on the improvment on hardware from R1 (Revision-1) to R3 (Revision-3, **Fig. 1**).

1) Announcement and Display Apparatus:: Since we want to make the total size of robot small, the distance to project is set at 1200 [mm] (the shortest on the used apparatus) and the size of the projected frame is as 36 [inch] types ($W740 \times H550$ [mm]). In R1 the projector is set downward in front of the robot, and the frame is directly projected on a running surface (**Fig. 3**(a)). The lens must be positioned at the height of 1200 [mm] from the running surface to keep the lenght of the light path, so the robot is 1470 [mm] height totally including the length of the projection equipment. The height of R1 is about the same as the 11-year-old Japanese's average height, and the children younger than schoolchildren may be threatened. So in R3 as a new design we make the projector installed upward and the frame is reflected in the mirror which is right above the projector then it is projected on a running surface (**Fig. 3**(b)). The total height of the robot is reduced to 1020 [mm] setting the projector upward at the height of 800 [mm] from a running surface, using the mirror with the size of $D140 \times W190$ [mm] at the height of 1000 [mm], then we could secure the lenght of the light path at 1200 [mm]. So the height of R3 is lower than kindergartener's average height. The position of the robot's center of gravity becomes lower by making the total height of the robot lower, and the robot becomes more steadily on moving. The height of the robot can be made still lower when the attachment position of the projector makes lowered, but if the distance between the projector and the mirror becomes longer we have to use bigger mirror. Large mirror is dangerous, so in R3 we adopted the mirror of the size mentioned above which is smaller than the robot's width.

2) Relation between Mobile Mechanism and Preliminary-Announcement Apparatus:: The mobile mechanism consists of two front driving wheels and two rear followers. So the robot can move forward or backward and perform revolution centering on the arbitrary point on the line which connects the axles of two driving wheels on either side. There was a slight gap between the scheduled course and the actual running course in R1 (**Fig. 4**(a)), since the start position to draw the scheduled course and the position of the axles of driving wheels were not in agreement anteroposteriorly. So in R3 (**Fig. 4**(b)) we moved the axles of driving wheels forward from the main body of the robot and the attachment angle of the reflecting mirror was adjusted, so that the projected frame was also brought close to the robot in order to correspond the drawn course with the running course correctly. Consequently, the position of the wheel axles and the position of the lower edge of the projected frame can be in agreement at 30 [mm] forward from the front of the robot, and the drawn course and the running course can be completely in agreement.

B. Software

The software program was built using Microsoft Visual C++ 6.0 on Windows 2000. The composition of the program is invariant, when moving the course decided beforehand or when receiving instructions from some input equipment, such as joystick, in real-time. When the program starts, a window is created, a timer is set up, and three threads (the

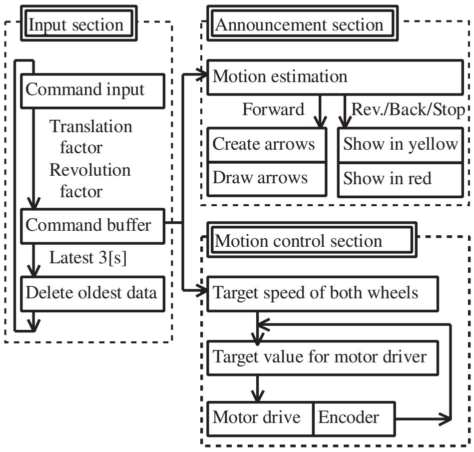


Fig. 5. Three sections in program

instruction value input, the mobile (driving wheels) control, and the OpenGL picture display) are started. Each thread is executed by the cycle time of 50 [ms] simultaneously. The outline and the relation among these threads are shown in **Fig. 5**.

The preliminary-announcement and display of operation is given until 3-second-later. Instruction values are kept for 3 seconds after the instruction is input, then the operation will be performed, since the robot indicates the operation until 3-second-later after the present as preliminary-announcement.

1) Instruction Value Input:: The robot takes into the instruction value J_x ($-1000\sim+1000$) as the amount of revolution and the instruction value J_y ($-1000\sim+1000$) as the amount of going straight in every 50[ms]. Input equipment is the *Side Winder Force Feedback 2* by Microsoft Corp. as a joystick and *JC-U912BK* by Elecom Co. as a game-pad. A plus value is acquired if the stick is pulled to the front, and a minus value is gotten when the stick is pushed to backward, since the joystick is a flight simulator type. The robot is made to move forward when a stick is pushed to backward (a minus value) in order to make the operator's feeling and the robot's motion in agreement. The same feeling of operation is also set on the game-pad. Moreover the dead-band is installed around zero settings of the stick when taking in the instruction value.

2) Mobile Control:: The speed instruction values which are taken in from the input equipment are always accumulated for 3 seconds in the instruction buffer (60 arrays for each instructions in every 50 [ms]). The instruction value at 3 seconds ago is used to calculate the target value at that time to control the mobility. Since the mobile mechanism is a two-driving-wheel type, going straight or revolution is controlled by the differential rotation of driving wheels on either side. Here the robot's motion is controlled by dividing the maximum speed of motion, which can be realized with rotating the driving wheel, into the going-straight part (translation factor) and the revolution part (revolution factor) (**Fig. 6**). The maximum speed of motion by rotation of the driving wheel is calculated by the following equation while

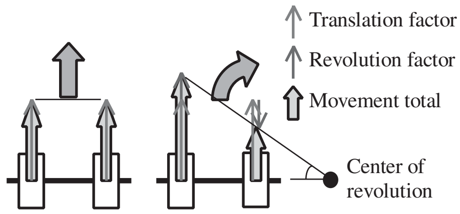


Fig. 6. Motion control

the motor reduction ratio is 50 and the diameter of the wheel is 100 [mm].

$$3000/60[\text{rps}] \div 50 \times 100\pi[\text{mm}] = 314[\text{mm/s}] \quad (1)$$

The maximum speed of motion is set at 250 [mm/s] securing the margin given to the drive system, and it is divided by going-straight : revolution $= 18 : 7$. When it is divided into $1 : 1$, distribution to revolution is too large. In this case, when only the greatest instruction value on going straight is input ($J_y = -1000$) the robot moves forward by 125 [mm/s] (both wheels on either side rotate at 2.5 [rad/s]). However, if $J_y = -1000$ and $J_x = 1000$ are input in order to make a right turn, for example, although the left wheel will be rotated at the maximum speed of $125 + 125 = 250$ [mm/s] (5.0 [rad/s]), the right wheel will stop by $125-125 = 0$ [mm/s] (0 [rad/s]), so the robot will do revolution centering on the right wheel. The robot will not move forward in spite of recieving the greatest going-straight instruction value, so the operator may feel it unnatural (refer to the right part in **Table II**). Then trial and error were repeated and the distribution ratio of going-straight : revolution was determined as $18 : 7$ (refer to the middle part in **Table II**). From this setting, the target speed of wheels on either side V_1 and V_2 [mm/s] becomes as the following.

$$V_1 = \left(\frac{18}{25} \times \frac{J_y}{1000} + \frac{7}{25} \times \frac{J_x}{1000}\right) \times 250 \quad (2)$$

$$V_2 = \left(-\frac{18}{25} \times \frac{J_y}{1000} + \frac{7}{25} \times \frac{J_x}{1000}\right) \times 250 \quad (3)$$

However the revolution radius in revolution operation of robot will change depending on the amount of going-straight instruction value even with the equations (2) and (3) also with the same revolution instruction value. In this case, the revolution angular velocity around the center of revolution is constant (the middle part in **Fig. 7**). So we made the revolution radius constant by multiplying the revolution instruction value J_x by the correction coefficient $|Jy|/1000$, when the revolution instruction value is fixed even with any amount of a going-straight instruction value (the bottom part in **Fig. 7**). The target speed of wheels on either side V_1 and V_2 by this setting becomes as the following.

$$V_1 = \left(\frac{18}{25} \times \frac{J_y}{1000} + \frac{7}{25} \times \frac{J_x}{1000} \times \frac{|J_y|}{1000}\right) \times 250 \quad (4)$$

$$V_2 = \left(-\frac{18}{25} \times \frac{J_y}{1000} + \frac{7}{25} \times \frac{J_x}{1000} \times \frac{|J_y|}{1000}\right) \times 250 \quad (5)$$

TABLE II

ROTATION SPEED OF EACH WHEEL DEPENDING ON SPRIT RATION

Motion	Input	18:7		1:1	
		left	right	left	right
straight	J_y=−1000 J_x=0	$180+0=180$ [mm/s] (3.6 [rad/s])	$180-0=180$ [mm/s] (3.6 [rad/s])	$125+0=125$ [mm/s] (2.5 [rad/s])	$125-0=125$ [mm/s] (2.5 [rad/s])
large turn	J_y=−1000 J_x=500	$180+35=215$ [mm/s] (4.3 [rad/s])	$180-35=145$ [mm/s] (2.9 [rad/s])	$125+35=160$ [mm/s] (3.2 [rad/s])	$125-35=90$ [mm/s] (1.8 [rad/s])
small turn	J_y=−1000 J_x=1000	$180+70=250$ [mm/s] (5.0 [rad/s])	$180-70=110$ [mm/s] (2.2 [rad/s])	$125+125=250$ [mm/s] (5.0 [rad/s])	$125-125=0$ [mm/s] (0.0 [rad/s])
spot revolution	J_y=0 J_x=1000	$0+70=70$ [mm/s] (1.4 [rad/s])	$0-70=-70$ [mm/s] (−1.4 [rad/s])	$0+125=125$ [mm/s] (2.5 [rad/s])	$0-125=-125$[mm/s] (−2.5 [rad/s])

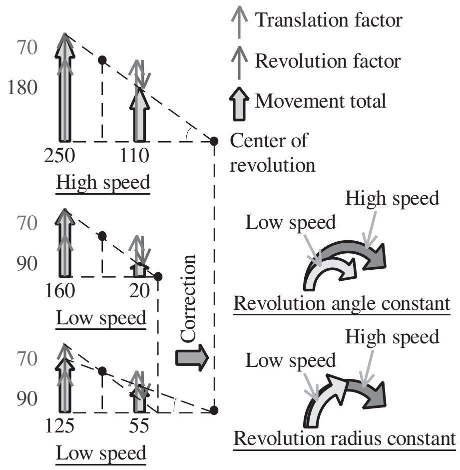


Fig. 7. Correction to keep position of ceneter of revolution

However the amount of revolution will become zero when the going-straight instruction value J_y is zero, so the operation of the spot revolution only with the revolution instruction value J_x will be impossible even with equations (4) and (5). So we decided to use different equations to calculate the target speed of wheels on either side depending on the amount of the going-straight instruction value J_y. That is, the revolution radius will be irregular when the going-straight instruction value is small even if the revolution instruction value is constant. The operation of robot becomes unstable and discontinuous when the instruction value is input by manual operation in real-time only with a simple categorizing and changing about the target speed of driving wheels. So we decided to multiply the revolution instruction value J_x by the correction coefficient $(1000 - 9 \times |Jy|)/1000$ in case of $|Jy| < 100$. Changing about the correction coefficient by the going-straight instruction value J_y is shown in **Fig. 8**. The target speed of wheels on both sides V_1 and V_2 by this setting become like the following equations.

$$V_1 = \left(\frac{18}{25}\times\frac{J_y}{1000}+\frac{7}{25}\times\frac{J_x}{1000}\times\frac{1000-9\times|J_y|}{1000}\right)\times 250 \tag{6}$$

$$V_2 = \left(-\frac{18}{25}\times\frac{J_y}{1000}+\frac{7}{25}\times\frac{J_x}{1000}\times\frac{1000-9\times|J_y|}{1000}\right)\times 250 \tag{7}$$

The distance which the robot should progress during the control cycles of 50 [ms] and the rotation angle which the driving wheels should rotate in the meantime can be calculated, when the target speed of wheels on either side V_1 and V_2 is decided. And the target count value of encoder attached with the driving motor in each control cycle can also be computed to control integrating from the starting time to the present. We only have to give the voltage instruction value to the motor driver and just to drive the motor so that the difference between the target count value and the present count value measured on the counter board will be zero.

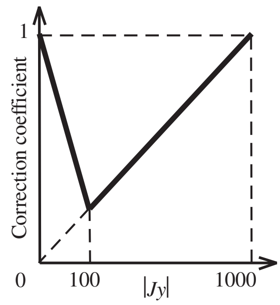


Fig. 8. Continuous and stable correction coefficient

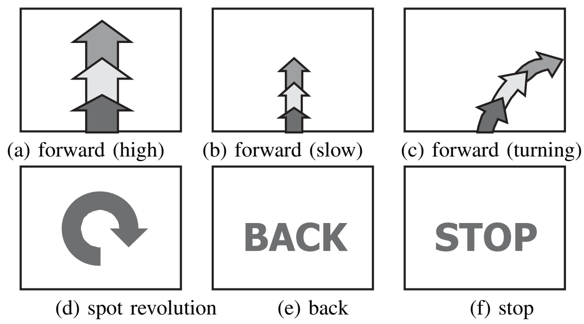


Fig. 9. Sign for motion

3) OpenGL Picture Display:: On the developed robot, we decided to display the scheduled course and the states of operation in the 2-dimensional frame which the projector projects on a running surface. The state of operation to display is roughly divided into four kinds, ”moving forward”, ”spot revolution”, ”going back”, and ”stop” (**Fig. 9**).

(1) *Distinction of state of operation:* First the state of operation to display is distinguished from the speed instruction value during the latest 3 seconds which is taken in from some input equipment and accumulated in the instruction buffer (60 arrays).

- There is some instruction whose going-straight value is minus (moving forward). → "Moving forward"
- There is some instruction whose going-straight value is zero, but the revolution value is not zero. → "Spot revolution"
- There is some instruction whose going-straight value is plus (going back). → "Going back"
- There is some instruction whose going-straight value and the revolution value are zero at the same time. → "Stop"

The states of operation are displayed independently even when two or more states of operation are distinguished simultaneously. So two or more states may be displayed in the frame at the same time, for example, when carrying out "moving forward" then "stop".

(2) *Contents to display and method to display:* The projector equipped on the developed robot is only one set and it can project one frame of the fixed size to the decided position in front of the robot. In displaying the states of operation the treatment in case of "spot revolution", "going back", and "stop" is the same, and the sign or the characters will be displayed.

a) *Moving forward:* Although the scheduled course drawn by the method using light-ray is a simple line (afterimage of light spot), by the method using projection the moving forward is expressed with the arrows in which the scheduled course is set as the long axis of the arrows considering the intelligibility at the first sight. The drawn arrow expresses the direction of motion directly, and the speed of motion can be announced with the length of the arrow. The scheduled course from the present to 3-second-later can be displayed in the projected frame considering the size of the frame and the mobility of the robot. If the scheduled course during 3 seconds is expressed with one arrow, the length only shows the average speed for 3 seconds. So three arrows classified by color for each second are connected and displayed. Considering that urgency increases when the arrow comes closer to the robot, the course from the present to 1-second-later is expressed in red arrow, the course from 1-second-later to 2-second-later is in yellow arrow, and the course from 2-second-later to 3-second-later is in green arrow referencing the classification by color of the traffic signal. Furthermore thinking that the danger also increases when moving rapidly, the width of arrow is adjusted according to the speed of motion. Namely, as for an arrow, not only the length but the width changes according to the speed of motion.

Square polygons are created from 60 pieces of the speed instruction for 3 seconds in every 50 [ms] respectively, they are connected perpendicularly and three arrows are formed. In addition, the polygons at the end portion of each three arrows are displayed after it is transformed so that the arrows may look like the correct form. The arrow is formed with from its base toward the end using from the old instruction value to the new instruction value respectively. Suppose the three arrows are created with 60 polygons using the speed instruction value from the instruction buffer and they are connected (**Fig. 10**(a)). If a new speed instruction value is

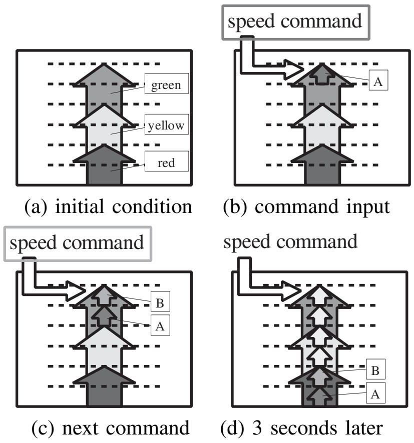


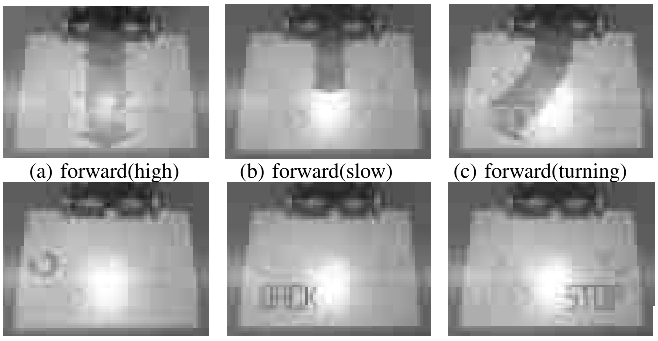
Fig. 10. Flow of data

taken in, the polygon A which is created using the new value is arranged at the top of the green arrow while shifting 60 old polygons to the base of the arrows (toward the robot). (**Fig. 10**(b)). The tip of this polygon A (top of the green arrow) shows the position of the robot at 3-second-later. If the next speed instruction value is taken in, the polygon A which has been at the top of the green arrow previously is shifted to the base of the arrows (toward the robot), and the polygon B which is created using the new value is arranged at the top of the green arrow. (**Fig. 10**(c)). Thus polygon A shifts to the base of the arrows (toward the robot) one by one as times goes on, and it reaches the base of the arrows 3 seconds later. Then that speed instruction value is performed and the robot moves in that manner. (**Fig. 10**(d)).

The rate of the length of the polygon along the direction of the course to the robot's speed of motion was determined by trial and error so that the arrows might agree with the actual movement of the robot. Moreover the rate of the width of the polygon to the amount of the speed instruction was also determined by trial and error considering the appearance of the arrows. Furthermore all polygons are connected after calculating those inclination and carrying out coordinate transformation when connecting perpendicularly with using the instruction value J_x for revolution and the instruction value J_y for going straight. The form of each polygon is adjusted so that the scheduled course may be expressed smoothly even if the speed instructions of not only going straight but also arbitrary revolving operation are given. By repeating these procedures, the scheduled course can be displayed correctly.

b) *Spot revolution / Going back / Stop:* The sign on both sides for spot revolution and the characters of "BACK" for going back and "STOP" for stop are displayed in the frame respectively. These are always displayed in light gray, while being displayed in yellow when the operation is performed within 3 seconds and being in red when the operation is performed at the present time.

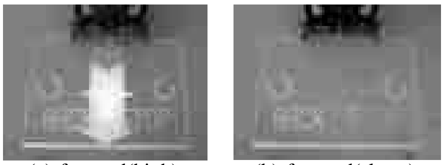
The example of the designed preliminary-announcement and display frame is shown in **Fig. 11**. In addition the frame with the background color in black is also prepared for a



(a) forward(high) (b) forward(slow) (c) forward(turning)

(d) spot revolution (e) going back (f) stop

Fig. 11. Projected frame



(a) forward(high) (b) forward(slows)

Fig. 12. Changing background color

bright running surface (**Fig. 12**).

IV. QUESTIONNAIRE EVALUATION

A. Purpose

It aims that various subject persons evaluate the intelligibility on the preliminary-announcement and display of the future direction of motion and speed of motion using the projector. Especially it notes whether the evaluation of intelligibility will differ according to gender or generation. Furthermore, it considers as an opportunity to widely recieve the opinion, comment, etc. about the research on preliminary-announcement and display of the robot's future operation.

B. Method

We exhibited the developed robot to the *2005 international robot exhibition* (sponsorship: Japan Robot Association and Nikkan Kogyo Shimbun Ltd., November 30, 2005 to December 03, at Tokyo International Exhibition Hall) and we had some visitors reply to the questionnaire.

C. Procedure

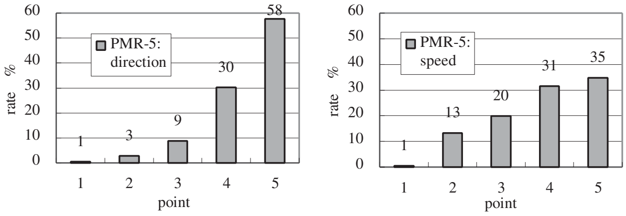
We asked the respondents freely look at the mobile robot moving while the information is projected on a running surface, after explaining the background and purpose of the research, the proposed method to preliminary-announcement and display the forthcoming operation, the total composition of the robot, etc. The robot also operated variously along the course decided beforehand or under the real-time operation. And we had the respondent reply to the questions set up as follows.

Please circle a suitable place and fill out freely.

◇ The direction of motion from now is announced beforehand by the direction of the course which consists of the arrows.
(unclear) 1 - 2 - 3 - 4 - 5 (intelligible)

TABLE III
SUBJECT PERSONS

sex	age								total
	10-	20-	30-	40-	50-	60-	70-	no	
male	6	39	43	35	35	16	2	9	185
female	1	6	3	3	0	0	0	3	16
(no)	0	3	4	1	0	0	0	3	11
total	7	48	50	39	35	16	2	15	212



(a) direction of motion (b) speed of motion

Fig. 13. Points

◇ The speed of motion from now is announced beforehand by the length of the course which consists of the arrows.
(unclear) 1 - 2 - 3 - 4 - 5 (intelligible)

◇ Fill in your opinion, comment, etc. on PMR-5 freely.

Especially we kept in mind that the intelligibility should be evaluated not relatively but absolutely.

D. Result and discussion

We obtained the replies from about 200 persons during four days. The composition of respondents according to gender and generation is shown in **Table III**. The respondents' rate to evaluation point about the direction of motion and the speed of motion is summarized and shown in **Fig. 13**. The average of the evaluation point and the average according to gender and generation are shown in **Table IV**.

The average evaluation point about the direction of motion is 4.5 points, so we obtained the evaluation that it is intelligible in general. The average evaluation point about the speed of motion is 3.9 points, so we obtained the evaluation that it is fairly intelligible. In addition, on the robot announcing the scheduled course by the afterimage of light spot with the laser pointer as the light source, which is exhibited at the same time, the average evaluation point about the direction of motion and the speed of motion is 2.5 and 2.8 respectively. The projector system developed the light-ray

TABLE IV
EVALUATION POINTS

	direction	speed
total	4.5	3.9
male	4.4	3.9
female	4.8	4.4
10∼	4.6	4.4
20∼	4.5	4.0
30∼	4.5	3.9
40∼	4.5	3.8
50∼	4.4	4.1
60∼	4.4	3.7

system as mentioned in Section III and it has come up as we aimed.

Female persons evaluate higher about both the direction of motion and the speed of motion than male persons on the whole. However the tendency of variation in evaluation is almost the same. The tendency that as younger the respondent is as higher the evaluation is about both the direction of motion and the speed of motion. But it cannot say that the evaluation differs greatly. It is conspicuous that the evaluation is somewhat high at younger people and the evaluation is a little low in elderly people about the speed of motion.

Various opinions have been obtained in the free entry column. Those are classified according to contents, and the examples are listed and considered in the following.

1) Projection system:: We have received many friendly opinions to using the projector.

- It is very intelligible.
- It is good since it is intelligible at a glance.
- It is intuitive and intelligible, and we can understand even without explanations.
- Even if who sees, many information is displayed intelligibly so it is nice.

2) Environmental conditions:: Since it is the system projected on a running surface, the indications on environmental conditions have been expected.

- How does it cope with in case of the uneven running surface?
- The question is whether the projected frame is legible in a bright field.
- Since it is not only the place where the running surface is clean, I hope the robot can cope with various conditions.

The robot can accommodate to the brightness and the color of the running surface to some extent by changing the background color or the display color, etc. which is explained in section III. When we described to the respondents who asked the question on site and we showed the frame changing its background color, they could be convinced on our working on countermeasures. However since the coverage is restricted and the robot can cope with to some extent in the same manner, it is practical that the projection system will be used in the indoor environment where the conditions are prepared to some extent. Moreover since the field to project is premised on being a flat plane, the distortion will arise on the scheduled course when the frame is displayed on uneven or inclined running surface. However we think there are few cases where precise coincidence between the displayed course and the actual moving course is necessary. Even if the display is not exact, rough movement of robot can be understood and such information is also effective. So the environmental limitation to some extent is assumed and special compensation is not considered right now.

3) Projection on a running surface in front of the robot:: There are some indications to projecting on a robot's running surface and it is only ahead of the robot.

- It is a problem that the place where the surrounding people have to look at is the ground.
- If the height of the robot is slightly lower, persons will look at the frame on ground with more attention.
- It will be hard to check the frame, when looking from the back of the robot.

As for the type projected on a running surface by the light-ray system or the projector system, there is a problem that the position to display some information separates from the main part of the robot. If there is a wide gap between the direction of seeing the robot and the direction of looking the information, the original function and usefulness of the robot may be disturbed. The relation between the size of the main part of the robot and the size of the frame to display is also a future subject to examine. The opinion that it is difficult to recognize the announcement from robot's back is naturally-expected. If operation of going back is forbidden to the robot the safety will be satisfied since the robot will not go to the place where the scheduled course is not displayed. However going back operation is allowed on the developed robot, so we will examine increasing the number of the projector and showing the information at robot's backside.

4) Arrow:: There are the following opinions about the arrows to display the scheduled course and the color to classify according to the time.

- It is good since it turns out where the robot will actually pass.
- It is good especially that the place where the robot will stop can be checked in advance.
- Isn't it better to use red color abundantly to display the arrow when the robot's speed of motion is high?
- More impact in expression is better so that the arrow may become conspicuous. I hope further improvement, for example, by using various and bright colors.
- We can understand what to indicate generally at a glance, even though the exact rule like displaying the scheduled course until 3-second-later is unclear.

It is especially favorable that the arrows become shorter gradually and the robot seems to stop at the position of the end tip of the arrow when the robot stops. There is no comment on changing the width of the arrows according to the speed of motion, since it might be hard to notice or it is accepted unconsciously. In the exhibition the arrows are classified by color according to the time. They should also be considered classifying by color according to the amount of the speed of motion or using the classifications according to the time and the speed together. We want to compare and examine in future about the issue. Various information can be distinguished and shown by using various colors, however there is also a shortcoming that the rules we have to understand will increase. Then we think that it is desirable to reduce the number of basic color as much as possible and it is better to use gradation abundantly. Moreover showing the space where the robot will take over on the passage will also be considered comparing with the case that only a line including arrows shows the scheduled course.

5) Other operations:: There are also opinions on displaying the characters for going back and stop, although there is no indication to the sign for spot revolution.

- BACK or STOP seems not always necessary to be displayed.
- It is unclear to announce beforehand the changing of motion and the timing using color on BACK or STOP.

We think that the characters suddenly displayed in a plain frame gives abrupt impression so the characters are always shown in light gray even if it is unnecessary. However not only changing the color but also changing as solid color / appearance may be more intelligible to invite attention to changing the operation. We want to compare and examine with blinking (with adjusting its frequency), although the changing in color which imitates the traffic signal might be easy to understand in terms of common sense.

6) On the whole:: Many friendly opinions we have obtained and there is almost no critical one.

- It is interesting!!
- It is promising.
- Please inquire so that the application range will widely spread since it is an unique research.

As mentioned above we could have the respondents accept the importance and the necessity for this research. And a certain amount of evaluation has been obtained also about the solution which we proposed. It is worth considering to improve still more, and we will advance further referencing the obtained opinions.

V. Conclusion

This paper discussed the mobile robot PMR-5 with the preliminary-announce and display function which indicates the forthcoming operations to the people around the robot by using a projector. The projector is set on a mobile robot and a 2-dimensional frame is projected on a running surface. In the frame, not only the scheduled course but also the states of operation can be clearly announced as the information about movement. We exhibited the robot and about 200 visitors did the questionnaire evaluation. The average of 5-stage evaluation is 3.9 points and 4.5 points for the direction of motion and the speed of motion respectively. So we obtained the evaluation that it is intelligible in general. Female person evaluate higher about both the direction of motion and the speed of motion than male persons on the whole. However the tendency of the variation in evaluation is almost the same. The tendency that as younger the respondent is as higher the evaluation is about both the direction of motion and the speed of motion. But it cannot say that evaluation differs greatly. We could have the respondents accept the importance and the necessity for this research. And a certain amount of evaluation has been obtained also about the solution which we proposed. It is worth considering to improve still more, and we will advance further referencing the obtained opinions.

The developed mobile robot can draw the scheduled course from the present to 3-second-later. And the period to announce and the length of the scheduled course drawn on a running surface should set up from the size and the performance of the robot considering intelligibility from surrounding people.

Although it is satisfactory when moving a course decided beforehand, there is a problem that the maneuverability will become worse when an operator operates the robot directly with some input device like joystick, since some fixed time delay will always be installed in the control system. In this case, it is considered that operator's operation is predicted from his/her operating history and 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 includes the examination of the way to deal with the case that the operator operates contrary to the prediction and the case when the robot should suddenly stop to secure safety autonomously, with the method to predict the operator's operation and intention.

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 anybody so as to understand and judge at a glance from common sense. So questionnaire evaluation by subject persons without prior knowledge is also a future work.

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