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Experimental Examination in Simulated Interactive Situation between People and Mobile Robot with Preliminary-Announcement and Indication Function of Upcoming Operation

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***Abstract*— This paper presents the result of the experimental examination by "passing each other" and "positional prediction" in simulated interactive situation between people and mobile robot. We have developed four prototype robots based on four proposed methods for preliminarily announcing and indicating to people the speed and direction of upcoming movement of mobile robot moving on two-dimensional plane. We observed significant difference between when there was a preliminary-announcement and indication (PAI) function and when there was not even in each experiment. Therefore the effect of preliminary-announcement and indication of upcoming operation was declared. In addition the feature and effective usage of each type of preliminary-announcement and indication method were clarified. That is, the method of announcing state of operation just after the present is effective when a person has to judge to which direction he should get on immediately due to the feature that simple information can be quickly transmitted. The method of indicating operations from the present to some future time continuously is effective when a person wants to avoid contact or collision surely and correctly owing to the feature that complicated information can be accurately transmitted. We would like to verify the result in various conditions such as the case that traffic lines are obliquely crossed.**

I. INTRODUCTION

This research is aiming at proposing the method and equipment of preliminarily announcing and indicating to people in the surroundings the speed and direction of upcoming movement of mobile robot moving on two-dimensional plane.

The media (communication service) in intentional transfer between people have been changed with a text (telegram), sound (telephone), a picture (facsimile), an image (TV telephone), and multimedia (Internet PC). Recently, motion media (robot) are also proposed [1]. On the other hand, most conventional researches on non-verbal interface between people and a machine is related with the communication of information in the direction from people to a machine. For example, many researches on image processing of human gesture [2], facial expression [3], gaze, etc. have been made in order to determine the user condition and his action and intention for the communication between people and a machine, the operation and control of apparatus or equipment, etc. In contrast, there was few research on transferring the information of machine itself to people especially in robotic systems. Meanwhile information mentioned here means not the mental information such as virtual feeling determined from various factors as for facial expression of robot head [4], [5], [6], but the dynamic and kinematic information of robot itself. Concerning the internal condition of robot, displaying residual quantity of battery, internal temperature, etc. on a screen was carried out on a mobile robot [7]. And on representing upcoming movement and intention of robot, the projection function to shared space between people and a manipulator was proposed [8]. The experiment on industrial robot with several LEDs at the tip was reported to support feeding of handicapped people [9].

This paper presents the result of experimental examination in simulated interactive situation between people and four developed prototype robots based on four proposed methods as the preliminary-announcement and indication (PAI) of the speed and direction of upcoming movement to surrounding people.

II. PROPOSED METHODS

We proposed four methods categorized in two types to preliminarily announce and indicate the speed and direction of upcoming movement of robot (Table I) [10]. First type announces state just after the present ((a) lamp method and (b) blowout method), and second type indicates operations from the present to some future time continuously ((c) light ray method and (d) projection method). Validity and timing to preliminarily announce were evaluated and examined by using computer simulation at first [11]. Then four prototype robots (eyeball robot PMR-2, arrow robot PMR-6, light ray robot PMR-1, and projection robot PMR-5) were developed based on the four methods.

Eyeball robot PMR-2 (Fig. 1) is embodied the lamp method [12]. The speed of movement is expressed by the degree of eye opening – fully open at high speed, half open at low speed, and closed when stopped – displayed on the commercial omni-directional display, Magicball (R). The direction of movement is indicated by eye positioning – $0deg$ from frontal when going straight, $30deg$ when making loose turn, $60deg$ when making tight turn, and $90deg$ during on-the-spot rotation. Displaying like human facial expression makes it familiar and sociable for everyone.

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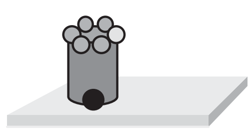
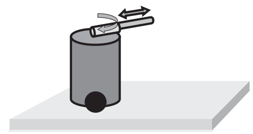
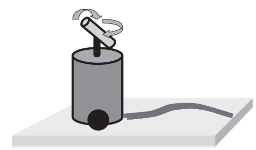
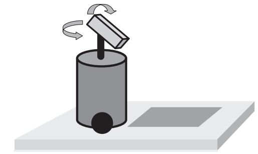
TABLE I
PROPOSING METHODS AND PROTOTYPE ROBOTS.

type	(1) announcing state of operation just after the present		(2) indicating operations from present to some future time	
method	(a) lamp 	(b) blowout 	(c) light ray 	(d) projection 
prototype robot	PMR-2 (eyeball robot)	PMR-6 (arrow robot)	PMR-1 (light ray robot)	PMR-5 (projection robot)
PAI device	omni-directional display	flat-panel display	laser pointer	projector
mobile mech. (max trans., max rot.)	two-wheeled drive 36 cm/s, 41.4 deg/s	two-wheeled drive 36 cm/s, 41.4 deg/s	two-wheeled drive 36 cm/s, 41.4 deg/s	two-wheeled drive 36 cm/s, 41.4 deg/s
size weight	D47×W48×H94 cm 24.5 kg	D47×W48×H44 cm 22.0 kg	D46×W48×H91 cm 30.0 kg	D50×W44×H100 cm 25.0 kg

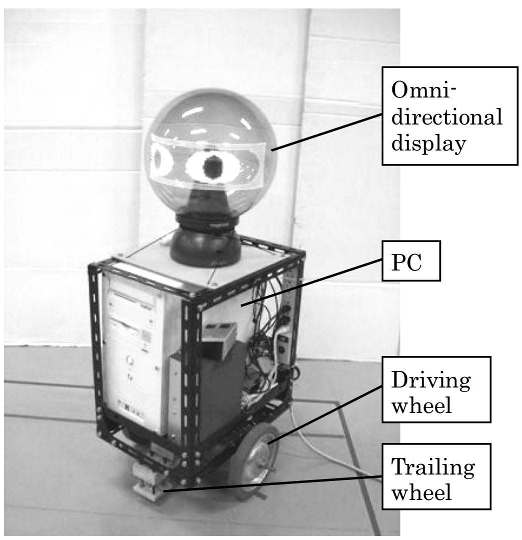


Fig. 1. Eyeball Robot, PMR-2

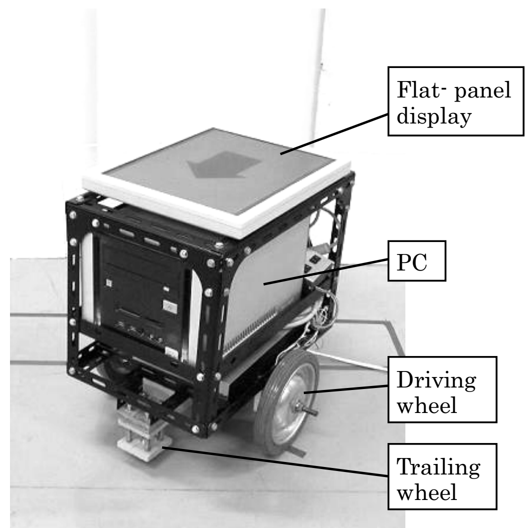


Fig. 2. Arrow Robot, PMR-6

Arrow robot PMR-6 (Fig. 2) indicates the upcoming state of operation by the sign (arrow) and characters shown on a commercial liquid crystal display (LCD), instead of some mechanism that imitates real blowout [13]. The speed of movement is expressed as the size (length and width) and color (based on traffic signal) of an arrow – large green at high speed, small yellow at low speed, and red characters when stopped. The direction of movement is described with the curved condition of the arrow – straight when going straight, curved when making loose turn, swerved when making tight turn, and rounded during on-the-spot rotation. The arrow expression is direct and intuitive and it is intelligible for everyone, since there is no ground for translation and interpretation between the sign and the movement.

Light ray robot PMR-1 (Fig. 3) is embodied the light ray method [14]. Reciprocating movement of reflecting mirror draws the scheduled route on running surface as the movement afterimage of radiation from seven laser pointers as the light source. Period to draw the scheduled route from the present is decides beforehand. Accordingly the speed of movement is expressed as the length of drawn route and the direction of movement is shown as the direction of drawn route itself. The strong point is situation on the way is definitely presented. For example, when the robot is moving to some point, it can be displayed whether it will go straight on the shortest route or it will go via some point to make detour or avoid something. On PMR-1 seven laser pointers, a commercial product in class 2 with output power of less than $1mW$ by red-color semiconductor laser at a wavelength of $635nm$, are used. Reciprocating movement of reflecting mirror is at a rate of $2{-}3Hz$ because visibility would become worse if less-bright radiation was moved too rapidly. On-the-spot rotation is expressed as fan-shaped movement of radiation on running surface.

Projection robot PMR-5 (Fig. 4) is embodied the projection method [15]. The frame reflected on the mirror just above the projector is projected on running surface. Main content of the projected frame is also the schedule route as well as the light ray robot. At the time of the questionnaire survey explained in the next paragraph, projected route is

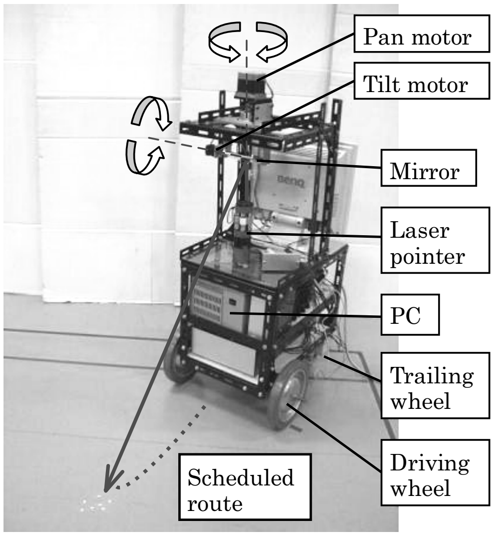


Fig. 3. Light Ray Robot, PMR-1

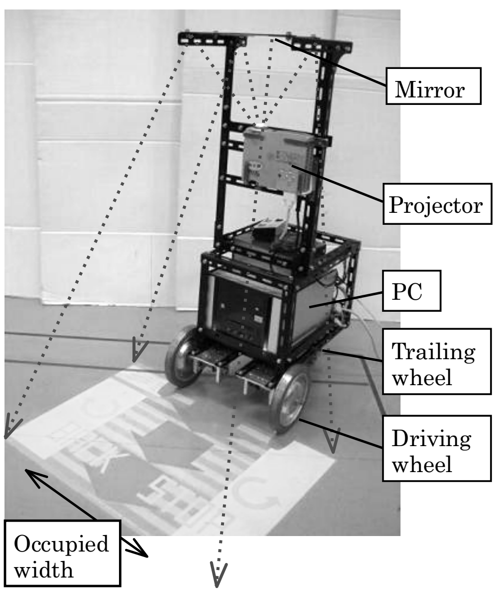


Fig. 4. Projection Robot, PMR-5

shown as chain of arrows in different colors indicating the time information during the drawn period of the route. For example, red arrow shows the route from the present to $0.5s$ later, yellow arrow shows that from $0.5s$ later to $1.0s$ later, and green arrow shows from $1.0s$ later to $1.5s$ later. The arrows can be curved freely. The width and length of arrows are also adjusted depending on the speed of movement, which makes it more intelligible for surrounding people. Furthermore the expression was modified so that not only the scheduled route but also the occupied width and area during robot's travelling are displayed on the frame by drawing a belt with the same width as that of the robot body. People will never have a contact nor collision with the robot and the safety will be secured only if they do not just step on the belt. The belt has semi-transparent striped pattern which moves towards robot synchronized with robot movement. Accordingly it looks like the belt is fixed to the floor and the robot moves with rewinding the belt. That makes easy to understand the meaning of the projected belt for people around.

These four prototype robots were exhibited at the 2005 International Robot Exhibition held in Tokyo. Questionnaires were adopted aiming to evaluate understandability of the preliminary-announcement and indication function of the speed and direction of upcoming movement on the four robots [16]. After explaining the background and purpose, proposed methods, composition of each robots, etc., to visitors and their looking at the prototype robots moving with announcing their upcoming operations, we had them to fill out questionnaires. Questionnaires were mainly five-stage-evaluations of intelligibility on the speed and direction of upcoming movement in each robot: (not understandable) 1 – 2 – 3 – 4 – 5 (understandable). We obtained about two hundreds replies in four days. To give official approval whether there is difference in the population mean of the parent population, the analysis of variance was made. One-way analysis of variance showed the significant difference in the level of 5% both on speed of movement and on direction of movement. This result shows that the understandability is different among four prototype robots. The projection robot PMR-5 received the highest evaluation score among the four robots both on the total average and on each gender and age groups. The examination of differences by gender and age suggested that some people prefer the friendly expressions by eyeball robot PMR-2 and the simple information and a minimum of information to be presented at one time by arrow robot PMR-6. Moreover, definite reason is not clear but it suggested that females accept the change in size of arrow and the change in color based on traffic signal in response to the speed of movement more favorably than males.

III. EXPERIMENTAL EXAMINATION

This chapter shows the main point of this paper; the description and result of the experimental examination by "passing each other" and "positional prediction" in simulated interactive situation between people and mobile robot.

A. *Experiment objective*

Previous questionnaire evaluation was subjective and sensory rating where we asked the respondents about their impression while watching the robot moving with indicating upcoming operation by the preliminary-announcement and indication function. On the contrary, setting up the simulation environment where people and robot are actually living together and having a certain task carried out, we aims at more objective assessment using the evaluation index with which some quantitative result will be obtained.

Meanwhile, the performances (resolution and updating cycle of displaying, etc.) of the preliminary-announcement and indication device equipped on each robot are different. Then in order to arrange the conditions as much as possible, movements of robot in the experiments were limited to the combination of three kinds of speed (high speed: $36cm/s$, low speed: $18cm/s$, and stop: $0cm/s$) and four kinds of direction (going straight: $R = \infty$, loose turn: $R = 100cm$, tight turn: $R = 50cm$, and on-the-spot rotation: $R = 0cm$).

B. Experiment description (1) Passing each other

1) Experimental setup:: Movement both of people and robot is measured using a motion capture system when they pass each other on a narrow passage (Fig. 5). From the state facing each other in the center at both ends of the straight passage (inner side of right and left lines drawn on a floor surface), a subject and a robot approach each other. The robot advances shifting to either left or right on the way so as to avoid the subject. We made the subject pass by the robot, avoiding touch with the robot by watching robot's preliminary-announcement and indication of its upcoming movement. In this situation, the effect of preliminary-announcement and indication function is observed and the feature of each method is detected as the difference of movement of the subject depending on the existence or the kind of preliminary-announcement and indication method. Here we paid attention to the distance between the subject and the robot and the change in speed of movement of the subject.

2) Experimental condition:: The width of passage is $180cm$ based on the standard for guidance of the "heart building law", and the length of passage (experimental area) is $630cm$ (Fig. 6). The measured range is $450cm$ and the entrance length for subject is $180cm$. The maximum of the measurement range of motion capture system is 450 by $180cm$ due to the arrangement of cameras and the resolution of measurement (less than $1cm$). Experimental area and measurement range are different because we wanted to set the length of passage as long as possible in the laboratory room.

We drew five lines at $60cm$ intervals at the beginning of walking for subject. And we had the subject progress by one interval along to the metronome ticking in every second for the first five seconds. This makes the initial speed of subject's walking adjust to $60cm/s$. Moreover a subject may contact with robot if he walks swinging his arms fully. It is also considered that the amount of swing of subject's arm affects the minimum approach distance between subject and robot. Then we asked the subject walk with his hands tied behind his back and fix both arms. The difference between right and left movements on waist is comparatively small while walking, and also twisting upper body may not have significant affect on waist movement. Then the reflectors for motion capture system were attached on both sides of subject's waist.

On each robot the reflectors were attached in right and left of the front face. The speed of movement was set as $36cm/s$. Since we could not prepare the entrance region for robot due to the restriction of experimental circumstance, the robot started to move three seconds after the subject began to walk. The shifting direction of robot – either right or left

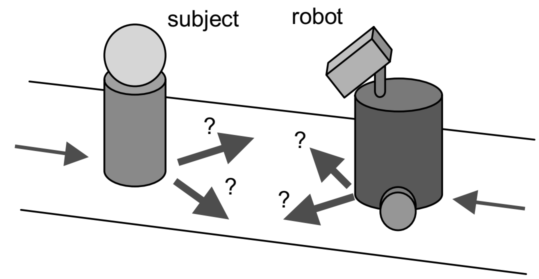


Fig. 5. Passing Each Other Experiment

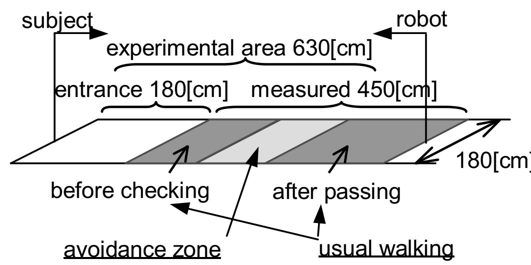


Fig. 6. Experimental Condition of Passing Each Other

– was set at random. The subject was only told that the robot progresses shifting to either right or left on the way.

Under these conditions experiments were carried out on five kinds of robot, PMR-2 (eyeball) and PMR-6 (arrow) which display the state of $1.5s$ later, and PMR-1 (light ray) and PMR-5 (projection) which indicate the operation until $1.5s$ later, and PMR-6 (robot with lowest height) not using preliminary-announcement and indication function.

3) Measured data:: Subjects are six male students of engineering course who look at these robots almost for the first time. Five kinds of robots moving on the passage while preliminarily announcing their upcoming movement were shown once for each. Then the experiments were carried out three times for each robot on each subject. The order of five robots in the experiment was made different arbitrarily both among six subjects and in the number of experiment on a subject, taking care that measured data might not be inclined.

The projected distance on running surface is used for distance evaluation as the minimum approach distance between subject and robot. Four robots have almost the same width and depth, but the height is different mainly due to the preliminary-announcement and indication device. The difference of robot's height may partly influence the approach distance between people and robot, however here we think that the difference among methods also includes the difference in height among four robots.

Change in speed in traveling direction (longitudinal direction of passage) was adopted as change in subject's speed of movement paying attention that the subject advances the passage avoiding the robot. It is difficult to acquire some meaningful result only from the amount of walking speed since the speed is widely varied in a gait cycle. Here instead of amount of walking speed, the difference of speed between at the time of usual walking and during avoidance operation is compared. If a subject begins to walk by $60cm/s$, the point ($330cm$ from the starting point) where he can see the changes of robot's preliminary-announcement and indication of its upcoming movement from going straight to shifting to either side is specified beforehand. Therefore we think the range of $90cm$ from that point as the avoidance zone where subject may move to avoid robot looking at its preliminary-announcement and indication. And the difference of average speed at the avoidance zone with that in other areas (the areas with usual walking, before checking robot's announcement and after passing each other) is calculated. Accordingly influence by variation of initial walking speed on each subject can also be reduced.

C. Experiment description (2) Positional prediction

1) Experimental setup:: The subject predicts the position of the robot at $1.5s$ later, which runs at random speed and in random direction, referencing the preliminary-announcement and indication of upcoming movement. We have a subject point out the position of the robot at $1.5s$ later as the tip of a stick ($115cm$ length). Both the tip position of the stick that a subject points out while predicting robot movement and the actual movement of robot are measured using the motion capture system (Fig. 7). The position pointed by the subject reflects what the subject recognizes looking at the preliminary-announcement and indication. Then the effect of preliminary-announcement and indication function and the feature of each method are estimated comparing the difference between the position pointed by subject with the actual position of robot at $1.5s$ later which is depending on the existence or kind of preliminary-announcement and indication.

2) Experimental condition:: On each robot the reflector for motion capture system was attached at the position nearby the place where the upcoming movement is indicated by preliminary-announcement device. We had the subject point out the position of the reflector at $1.5s$ later as the tip of stick. Concretely, in eyeball robot PMR-2 the reflector was attached in front of the sphere portion to display on omni-directional display. In arrow robot PMR-6 the reflector was attached in the center of edge that is made by front face and upper surface. The reflectors were attached in the lower part of front face in light ray robot PMR-1 and in projection robot PMR-5 respectively. Subject will be able to declare the position with sufficient accuracy when he points out the tip of stick at a lower level near the floor surface as the position of robot movement. However we think the recognition by subject about the future robot position will be better reflected as the tip position of stick when the direction of looking at preliminary-announcement and indication is made corresponding with the direction of looking at the tip of stick as much as possible.

The robot movement was designed using a random function so that a robot might move within the area of 450 by $300cm$ at random speed and in random direction (Fig. 8). Subject was told that the robot would not going out from the experimental area bounded by four lines before the experiment was performed. Moreover some space was prepared outside the experiment area as much as possible taking care that subject's motion might not be interfered.

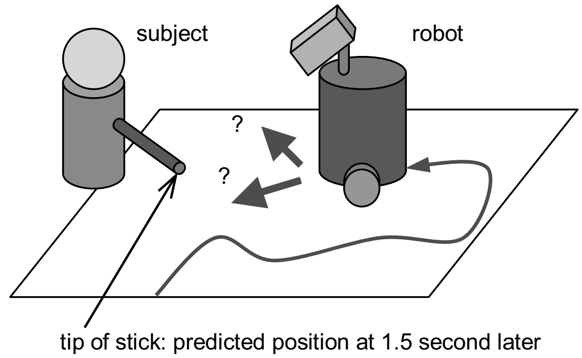


Fig. 7. Positional Prediction Experiment

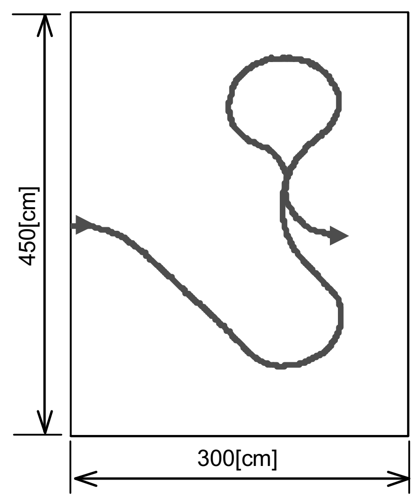


Fig. 8. Experimental Condition of Positional Prediction (Example of Robot Trajectory)

Under these conditions experiments were carried out on five kinds of robot that are the same as in passing each other experiment.

3) Measured data:: Subjects are eight male students of engineering course who look at these robots almost for the first time. Five kinds of robots moving by manual operation with preliminarily announcing and indicating its upcoming movement were shown and let subject understand the function and performance of each robot at first. Then experiments were carried out for $30s$ once for each robot on a subject.

Five patterns of robot movement for $30s$ were prepared and the movement of five robots made different for each subject. The order of five robots and the movement pattern of each robot for a subject were made different arbitrarily taking care that measured data might not be inclined.

The amount of position difference reflects the difference

TABLE II

MINIMUM APPROACH DISTANCE

robot	PMR-2 (eyeball)	PMR-6 (arrow)	PMR-1 (light ray)	PMR-5 (projection)	without announcing
Av. [cm]	31.2	29.6	25.6	32.1	14.0
SD [cm]	8.0	10.7	11.7	9.6	8.7

TABLE III

DIFFERENCE OF AVERAGE SPEED

robot	PMR-2 (eyeball)	PMR-6 (arrow)	PMR-1 (light ray)	PMR-5 (projection)	without announcing
Av. [cm/s]	6.4	7.4	15.8	11.3	21.1
SD [cm/s]	5.1	5.4	8.5	6.7	11.0

Fig. 9. Passing Each Other Experiment

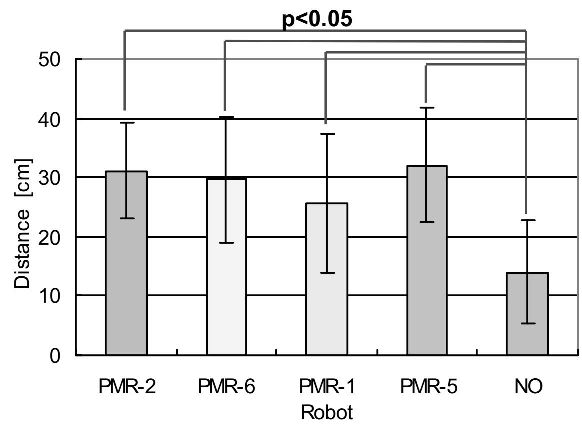


Fig. 10. Minimum Approach Distance

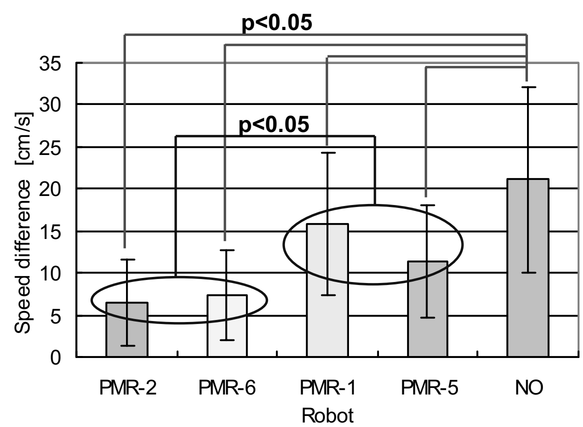


Fig. 11. Difference of Average Speed

between the movement recognized by subject and the actual movement of robot. The comparison is examined at the average and the maximum during $30s$.

D. Result and discussion (1) Passing each other

The experimental situation is shown in Fig. 9.

Longer the minimum approach distance (Table II, Fig. 10) is, the subject avoided the robot more in safety. The significant difference was observed between when there was preliminary-announcement and indication function and when there was not ($p < 0.05$). However significant difference was not confirmed among the methods of preliminary-announcement and indication.

The difference of average speeds (Table III, Fig. 11) shows variant movement compared with usual walking. And large amount of difference means unnatural movement when passed by the robot while avoiding. The significant difference was observed between when there was preliminary-announcement and indication function and when there was not ($p < 0.05$). Furthermore the speed difference was significantly smaller on the method of announcing state of operation at a time just after the present compared with the method of indicating operations from the present to some future time continuously ($p < 0.05$). This might be because subjects can understand certainly the direction of upcoming robot movement and determine the direction he should move to avoid the robot (right or left) immediately by announcing state of operation at a time just after the present.

E. Result and discussion (2) Positional prediction

The experimental situation is shown in Fig. 12.

Smaller the amount of position difference is, the subject recognized the robot position more correctly. The significant difference was observed on the average value during $30s$ (Table IV, Fig. 13) between when there was preliminary-announcement and indication function and when there was

TABLE IV

AVERAGE OF POSITION DIFFERENCE

robot	PMR-2 (eyeball)	PMR-6 (arrow)	PMR-1 (light ray)	PMR-5 (projection)	without announcing
Av. [cm]	21.2	19.2	17.3	11.7	30.0
SD [cm]	3.9	2.3	2.3	1.6	3.5

TABLE V

MAXIMUM OF POSITION DIFFERENCE

robot	PMR-2 (eyeball)	PMR-6 (arrow)	PMR-1 (light ray)	PMR-5 (projection)	without announcing
Av. [cm]	50.7	49.3	45.1	32.2	75.8
SD [cm]	9.4	6.4	6.5	8.3	10.3

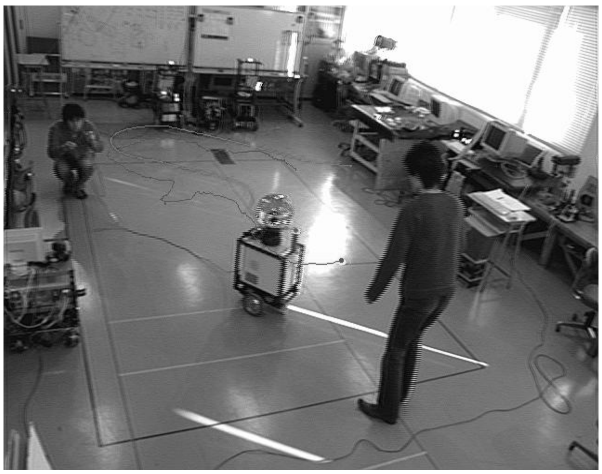


Fig. 12. Positional Prediction Experiment

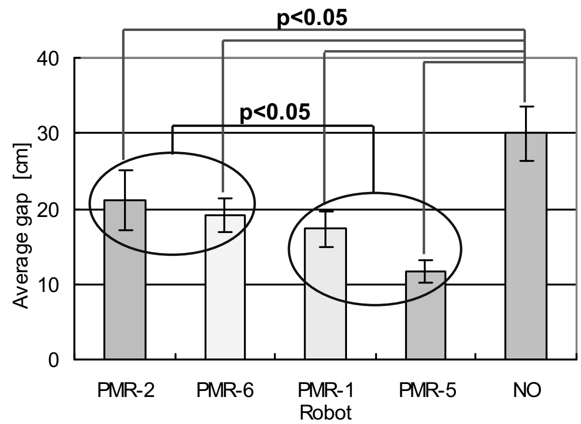


Fig. 13. Average of Position Difference

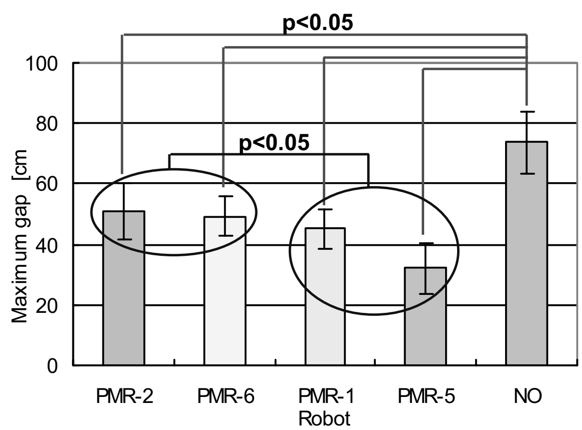


Fig. 14. Maximum of Position Difference

not ($p < 0.05$). Furthermore the position difference was significantly smaller on the method of indicating operations from the present to some future time continuously compared with the method of announcing state of operation at a time just after the present ($p < 0.05$). The same result was obtained on the maximum value during $30s$ (Table V, Fig. 14). Those are because the scheduled route of robot is presented and the subject can understand the robot position at $1.5s$ later correctly by the method of indicating operations from the present to some future time continuously.

Moreover in the type of indicating operations continuously, the significant difference is remarkable between the light ray robot PMR-1 and the projection robot PMR-5 both on average value and on maximum value. Although the scheduled route is displayed at $2-3Hz$ on the light ray robot due to the problem in the device mechanism, the occupied area is displayed at $20Hz$ on the projection robot. So subjects can always recognize the position of projection robot at $1.5s$ later correctly.

F. Summary of experiments

We have confirmed the effect of preliminary-announcement and indication of upcoming operation both on the experiments from comparison between when there was a preliminary-announcement and indication function and when there was not even if any method was applied.

We also confirmed the feature of the method announcing state of operation just after the present that simple information, like an alternative on either side, could be quickly transmitted, based on the fact that the difference between the average walking speed during avoidance operation and that at usual walking was small in the passing each other experiment. Therefore the method announcing state of operation just after the present may be effective when a person has to judge to which direction he should get on immediately.

On the other hand we confirmed the feature of the method indicating operations from the present to some future time continuously that complicated information, like variable movements which changes one after another, could be accurately transmitted, based on the fact that the difference between the subject's recognition and the actual robot operation was small in the positional prediction experiment. Therefore the method indicating operations from the present to some time may be effective when a person wants to avoid contact or collision with robot surely and correctly.

IV. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

This paper presented the result of the experimental examination by "passing each other" and "positional prediction" in simulated interactive situation between people and mobile robot. We have developed four prototype robots based on four proposed methods for preliminarily announcing and indicating to people the speed and direction of upcoming movement of mobile robot moving on two-dimensional plane. We observed significant difference between when there was a preliminary-announcement and indication function and when there was not even in each experiment. Therefore the effect of preliminary-announcement and indication of upcoming operation was declared. In addition the feature and effective usage of each type of preliminary-announcement and indication method were clarified. That is, the method of announcing state of operation just after the present is effective when a person has to judge to which direction he should get on immediately due to the feature that simple information can be quickly transmitted. The method of indicating operations from the present to some future time continuously is effective when a person wants to avoid contact or collision surely and correctly owing to the feature that complicated information can be accurately transmitted.

B. Future Works

Future plan includes continuing the experiment by various subjects and it is necessary to generalize the results. We have to verify the result even when the speed of robot movement is still faster. And also we would like to examine in various conditions, such as the case that traffic lines are obliquely crossed not facing each other but meeting suddenly or the case that some obstacles are scattered on the way.

V. ACKNOWLEDGMENTS

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