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Remote Control System for Mobile Robot with Semi-autonomous Control Based on Degree of Collision Danger

Takahiro Nagai, Takashi Yasuno and Akinobu Kuwahara

Graduate School of the University of Tokushima
2–1 Minami-Josanjima, Tokushima 770-8506, Japan
Phone/FAX: +81-88-656-7458
E-mail: {nagai-t, yasuno}@ee.tokushima-u.ac.jp

Abstract

This paper proposes a semi-autonomous remote control system for a mobile robot using the degree of collision danger. To successfully realize obstacle avoidance depending on the current condition, the degree of collision danger between the mobile robot and an obstacle is defined by using simplified fuzzy reasoning and is used to decide the priority of manipulation by an operator or autonomous navigation. Several experimental results using our developed legged-type mobile robot demonstrate the validity of the proposed semi-autonomous remote control system.

1. Introduction

In order to navigate a remote-controlled mobile robot safety and efficiently from a current position to a goal, an operator needs to improve his or her ability of environmental recognition, decision-making, and manipulation. This is because it is very difficult to obtain sufficient and accurate environmental information from various sensors, and the operator is apt to make mistakes in the manipulation of the mobile robot. To avoid operator mistakes including the misreading of data and erroneous manipulation, we consider that autonomous control is needed to support the operator's decision-making and manipulation.

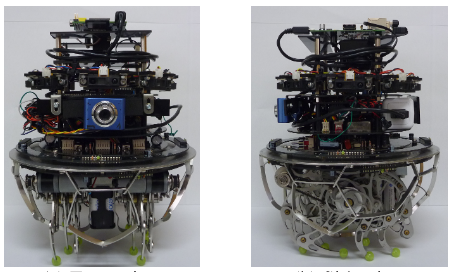
In the problem of mobile robot navigation, the most important aim is obstacle avoidance to guarantee safety. To achieve this aim, Maeda and Takegaki proposed an effective collision avoidance method for a mobile robot that applied fuzzy reasoning and production rules [1]. In this method, the mobile robot recognizes the degree of collision danger between itself and an obstacle by fuzzy reasoning, and decides the direction of avoidance from the degree of collision danger.

In this paper, we consider how to install autonomous control for obstacle avoidance and focus on the degree of collision danger as a weighted parameter between autonomous control and manipulation by an operator [2]. This approach reduces the load on the operator side. In order to ensure the validity of the proposed semi-autonomous remote control system, we developed a legged-type mobile robot (called Q-po3) and carried out several experiments using the robot.

2. Developed Teleoperation System

2.1 Developed mobile robot Q-po3

Figures 1(a) and 1(b) show the appearance of our legged-type mobile robot, Q-po3, developed to demonstrate the validity of the proposed semi-autonomous remote control system. This robot has an overall length of 220mm, an overall width of 215mm, and an overall height of 261mm, and is made up of communication, control, motor drive, leg, power supply (DC 12V), and external sensor sections. The leg section, which employs a multilink mechanism is based on the model of Strandbeest by Theo Jansen and has six legs each on the left and right sides. The operator can control the robot to go forward, reverse, stop, pivot turn, and spin turn. As external sensors, the robot is equipped with a USB camera to monitor the area around the robot and a distance range finder with eight IR sensors, which is rotated by a dc motor in order to measure the relative distance between the robot and obstacles in a wide scanning range.



(a) Front view (b) Side view

Figure 1: Developed mobile robot Q-po3

2.2 Hardware configuration

Figure 2 shows the hardware configuration of the teleoperation system. First, the operator decides the speed commands of the left and right legs, $v_r = R\omega_r$ and $v_l = R\omega_l$, respectively (R=7.5cm is the wheel radius), using a joystick-type controller which is connected to a PC in the base station. Next, the decided speed commands of the motor, ω_r and ω_l, are sent to an H8/3052F microcomputer by the wireless communication module mounted on the robot and are converted to PWM signals in order to drive the motors. After these processes, the traveling velocity v and angular velocity of rotation ω of Q-po3 are formulated as follows:

$$\begin{pmatrix} v \\ \omega \end{pmatrix} = \begin{pmatrix} \frac{R}{2} & \frac{R}{2} \\ \frac{R}{T} & -\frac{R}{T} \end{pmatrix} \begin{pmatrix} \omega_r \\ \omega_l \end{pmatrix} \quad (1)$$

where T=8.4cm is the distance between the legs on the left and right sides. Also, the velocities of the legs on the left and right sides, $(v_x, v_y)^T$ are calculated by

$$\begin{pmatrix} v_x \\ v_y \end{pmatrix} = v \begin{pmatrix} \cos\omega t \\ \sin\omega t \end{pmatrix} \quad (2)$$

In addition, the H8/3052F microcomputer sends the relative distances measured by the distance range finder to the PC. In the same way, a Raspberry Pi microcomputer delivers a movie from the USB camera to the PC. The sampling time of the sensor information and the operation log acquisition is set to 150ms.

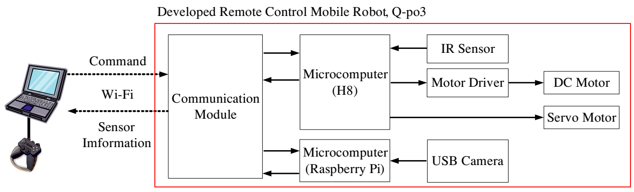
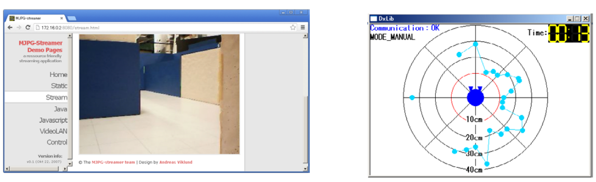


Figure 2: Hardware configuration

2.3 Visual user interface

To support the operator's manipulation of the remote-controlled mobile robot, we developed control software based on a visual user interface as shown in Figs. 3(a) and 3(b). The operator can recognize environmental conditions by looking at the movie obtained from the USB camera through the window, as shown in Fig. 3(a), and is informed of the relative distances between the robot and obstacles as shown in Fig. 3(b).



(a) USB camera image (b) Relative distance

Figure 3: Windows of control software

3. Proposed Semi-autonomous Remote Control System

3.1 System configuration

Figure 4 shows the configuration of the proposed semi-autonomous remote control system. This system consists of a part for estimating the degree of collision danger and a part for obstacle avoidance.

Generally, the degree of collision danger is estimated from the relative distance between the robot and the obstacle. However, in the case of the remote control system, the control system includes the operator, i.e., this is a human-oriented control system. Therefore, to estimate the degree of collision danger, consideration of the operator's manipulation (speed commands v_x and v_y) is needed. Otherwise, the operator will feel a sense of incompatibility with the manipulation of the robot. Thus, the operator's speed commands (v_x, v_y) and the relative distance measured by each IR sensor are used as input variables to estimate the degree of collision danger.

On the other hand, it is very important to avoid the collision with an obstacle by using the estimated degree of collision danger. In this paper, we propose a collision avoidance control algorithm that involves collecting the degree of collision danger in each direction and converting speed commands into actions to avoid obstacles depending on the current conditions, where priority is given to the operator's manipulation or the autonomous navigation.

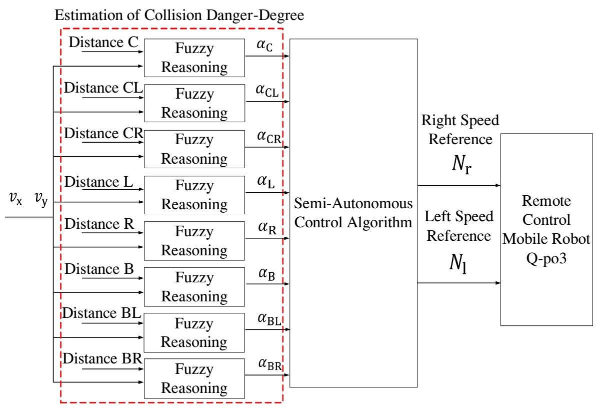


Figure 4: Configuration of proposed control system

3.2 Estimation of degree of collision danger

Generally, fuzzy reasoning has the ability to estimate certain information from uncertain information by applying tuned fuzzy rules. In this paper, we introduce a fuzzy reasoning method to estimate the degree of collision danger because of the uncertainty of the sensor information. The fuzzy reasoning procedure is briefly described as follows. The variables (v_x, v_y) and the relative distance measured by each IR sensor are input to the fuzzy reasoning engine and are converted into suitable linguistic variables that may be viewed as the labels of fuzzy sets. In this paper, the following eight linguistic variables are used: very slow (VS), a little slow (LS), a little fast (LF), and very fast (VF) for the speed commands (v_x, v_y), and very close (VC), a little close (LC), a little distant (LD), and very distant (VD) for the distance between the robot and obstacles. Fuzzy sets corresponding to each linguistic variable are defined by assigning the grade of triangular membership functions. We selected two grade values μ_{w0} and μ_{w1}(w=1-3) for each input for three fuzzy sets. Also, consequent sections determine the value from the linguistic variables of the inputs. These consequent sections are singleton variables $W_{i,j,k}$ (i, j, k=0,1,2) shown in Table 1. Therefore, the grade value of each consequent singleton variable is given by

$$\mu_{ijk} = \mu_i \cdot \mu_j \cdot \mu_k \tag{3}$$

where i, j, and k are each linguistic variable of the membership function. Finally, the degree of collision danger $\alpha(n)$, which is the output of the fuzzy reasoning engine, is obtained as

$$\alpha(n) = \frac{\sum \mu_{ijk} \cdot W_{ijk}}{\sum \mu_{ijk}} \tag{4}$$

Table 1: Parameters tuned by fuzzy rules

(a) v_x = VS

v_y \ Relative Distance	VC	LC	LD	VD
VS	1.0	0.0	0.0	0.0
LS	1.0	0.1	0.0	0.0
LF	1.0	0.2	0.1	0.0
VF	1.0	0.8	0.4	0.1

(b) v_x = LS

v_y \ Relative Distance	VC	LC	LD	VD
VS	1.0	0.0	0.0	0.0
LS	1.0	0.0	0.0	0.0
LF	1.0	0.1	0.1	0.0
VF	1.0	0.6	0.3	0.0

(c) v_x = LF

v_y \ Relative Distance	VC	LC	LD	VD
VS	1.0	0.0	0.0	0.0
LS	1.0	0.0	0.0	0.0
LF	1.0	0.0	0.0	0.0
VF	1.0	0.4	0.2	0.0

(d) v_x = VF

v_y \ Relative Distance	VC	LC	LD	VD
VS	1.0	0.0	0.0	0.0
LS	1.0	0.0	0.0	0.0
LF	1.0	0.0	0.0	0.0
VF	1.0	0.3	0.1	0.0

3.3 Obstacle avoidance control algorithm

To avoid erroneous manipulation by the operator and successfully avoid obstacles, we propose a speed reference determination method based on the estimated the degree of collision danger as follows:

$$\begin{pmatrix} N_r \\ N_l \end{pmatrix} = \begin{pmatrix} \left(1 - \frac{\alpha_m+\alpha_n}{2}\right) v_y - \left(1 - \frac{\alpha_p+\alpha_q}{2}\right) v_x \\ \left(1 - \frac{\alpha_s+\alpha_n}{2}\right) v_y - \left(1 - \frac{\alpha_p+\alpha_q}{2}\right) v_x \end{pmatrix} \tag{5}$$

where
if $v_x \geq 0$ and $v_y > 0$ then m=CL, n=C, p=R, q=CR, s=CR
if $v_x < 0$ and $v_y > 0$ then m=CL, n=C, p=L, q=CL, s=CR
if $v_x \leq 0$ and $v_y < 0$ then m=BL, n=B, p=L, q=BL, s=BR
if $v_x > 0$ and $v_y < 0$ then m=BL, n=B, p=R, q=BR, s=BR

The degree of collision danger is used to determine the reliability level of the operator's manipulation to guarantee sufficient safety against collision.

4. Experimental Results

To ensure the validity of the proposed semi-autonomous remote control system, three types of experiment (Type 1, Type 2, and Type 3) were conducted. Type 1 involved manipulation by only the operator, Type 2 involved passive obstacle avoidance control with the speed commands (N_r, N_l) set to zero when Q-po3 was less than 10cm from an obstacle, and Type 3 used the proposed semi-autonomous remote control system. Six subjects (A to F) were used as the operator. Three subjects (A, B, and C) carried out experiment Type 1 and Type 2. The other subjects (D, E, and F) only carried out experiment Type 3. All subjects understood the basic manipulations of Q-po3 and the information on the operation screen, and were given a rough map of the workspace in advance. In addition, all subjects were given about one minute to confirm the basic manipulations of Q-po3 before the experiments. The workspace of all experiments had some static obstacles.

Figures 5(a)-5(c) show the traveling loci of Q-po3 and Fig. 6 indicates the total operation time for each experiment. In the Type 1 experiment, although the total operation time was short, the robot did not reach the goal. In the Type 2 experiment, Q-po3 arrived at the goal without colliding with an obstacle. However, the total operation time was longer than in the other cases. In contrast, using the proposed semi-autonomous remote control system (Type 3), Q-po3 arrived at the goal without colliding with obstacles in a shorter operation time than that for the Type 2 experiment.

Figures 7-9 show transitions of the degree of collision danger for the front, front left and front right directions. In the Type 3 experiment, the degree of collision danger was smaller than that in the Type 1 and Type 2 experiments during operation. That is, the operator can choose the desired steering angle depending on the condition.

5. Conclusion and Future Work

In this paper, we proposed a semi-autonomous remote control system for a mobile robot using the degree of collision danger. Moreover, three types of experiment were conducted using our developed mobile robot system. As a result, it was confirmed that the proposed semi-autonomous control system is useful and effective as a human-oriented remote control system.

Future work is to apply the proposed system to a complex environment with both static and dynamic obstacles.

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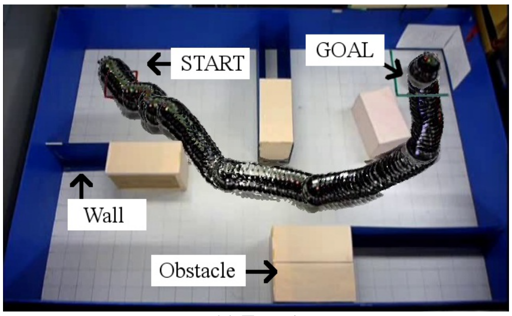
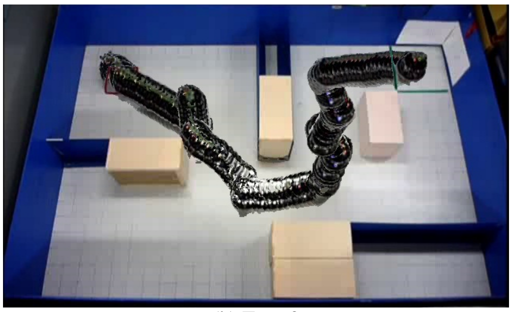
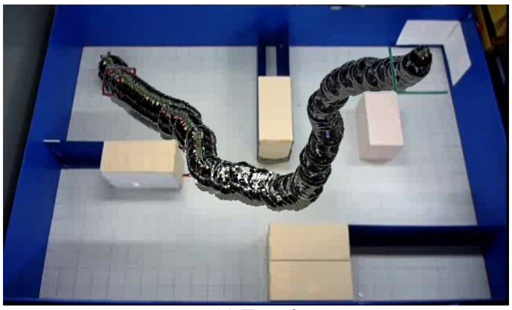
[2] T. Nakatani, T. Yasuno, K. Yamanaka and A. Kuwahara: Investigation of collision avoidance using vibration device for electric wheelchair support system, RISP International Workshop on NCSP, pp. 33-36, 2012.



(a) Type 1



(b) Type 2



(c) Type 3

Figure 5: Experimental results (loci)

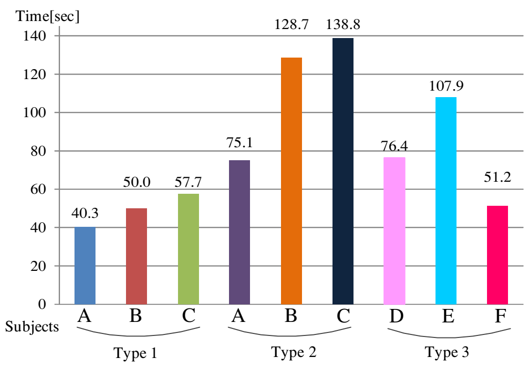
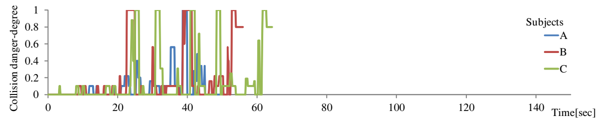
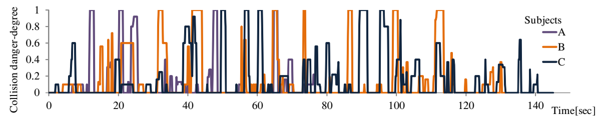


Figure 6: Comparison of total operation time



(a) Type 1



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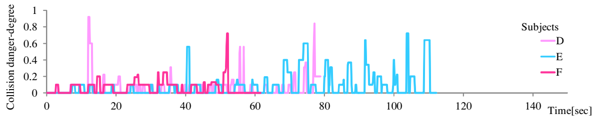
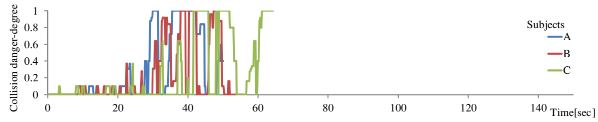
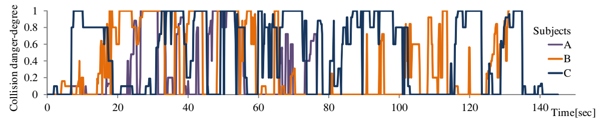


(c) Type 3

Figure 7: Degree of collision danger for C direction



(a) Type 1



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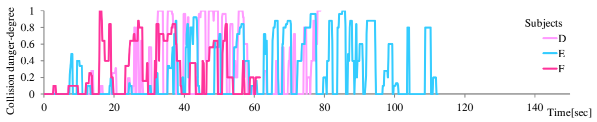
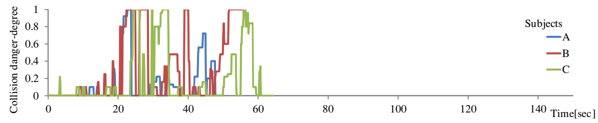
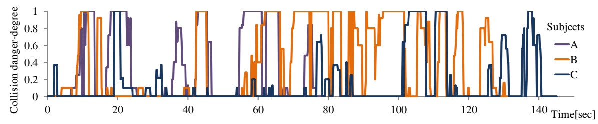


(c) Type 3

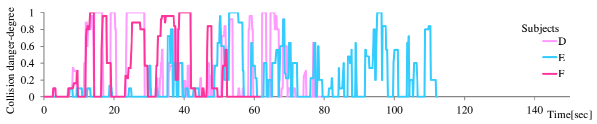
Figure 8: Degree of collision danger for CL direction



(a) Type 1



(b) Type 2



(c) Type 3

Figure 9: Degree of collision danger for CR direction