MULTI SCALE MOVING CONTROL METHOD
FOR AUTONOMOUS OMNI-DIRECTIONAL MOBILE ROBOT

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Abstract: This paper proposes a hierarchical moving control method for autonomous omni-directional mobile robot to achieve both safe and effective movement in a dynamic environment with moving objects such as humans. In the method, the movement of the robot can be realized based on prediction of the movement of obstacles by taking account of time scale differences. In this paper, the design method of the proposed method based on the virtual potential approach is proposed. In the method, modules that generate the potential field are structured hierarchically based on the prediction time to each problem. To verify the effectiveness of the proposed method, the numerical simulations and the experiments using a real robot are carried out. From the results, it is confirmed that the robot with the proposed method can realize safe and efficient movement in dynamic environment.

1 INTRODUCTION

Recently, various essential technologies of an autonomous mobile robot such as a self localization scheme, an environmental map formation and path planning, learning algorithm and communication are developed in the area of robot. In addition, a variety of service robots which offers service with the actual environment with other moving objects, including people are proposed and developed(B. Graf, 2004)-(R. Bischoff). A variety of tasks are required for such a service robot, but here we will focus on problems related to moving, which is the most fundamental and important of tasks. In the environment include humans, safe and efficient movement should be required. As for the movement of the autonomous mobile robot, the problem which has the various time scales, such as arrival to destination, the collision avoidance for the obstacle and the emergency collision avoidance for the sudden obstacle, occurs simultaneously. Therefore, the robot should keep coping with the problem according to circumstance.

This paper proposes a hierarchical moving control method for autonomous omni-directional mobile robot to achieve safe and effective movement in a dynamic environment with moving objects such as humans. The hierarchical control method considers a variety of prediction time to each action, such as destination path planning, obstacle avoidance within the recognizable range, and emergency avoidance to avoid spontaneous events. In the method, several modules for each action are composed in parallel. The vertical axis is prediction time scale in the control system. In the lowest module, the robot can move to goal safely and efficiently by planning from the environment information which is obtained in advance. On the other hand, in the higher module, the robot moves more safely by using the estimated information of obstacles based on shorter prediction time to avoid them. By integrating the output of each module, it is possible to realize the safe and efficient movement according to the situation.

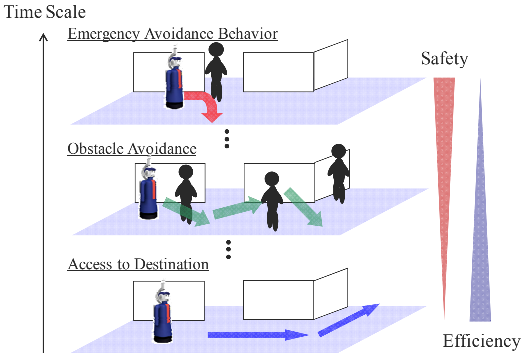

Figure 1: Problem Establishment for Action of Service Robot.

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In this paper, as one example of design method of the proposed control method, the design method which is based on the virtual potential method is presented (Khatib, 1986) (Y. Koren, 1991). Firstly, the module which generates the potential field based on each prediction time is formed hierarchically. Secondly, the virtual force which is derived from the respective potential fields is synthesized. Thirdly, the velocity command is decided on the basis of the resultant force. To verify the effectiveness of the proposed method, the numerical simulations which suppose the environment where the obstacle exists were carried out. Moreover, the experiments using the real apparatus of the autonomous omni-directional robot were carried out.

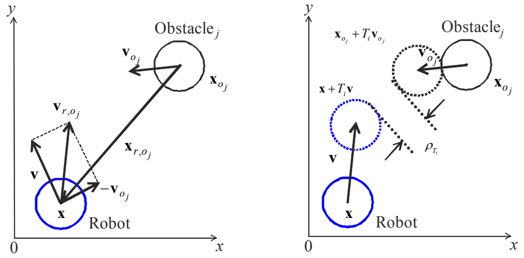


Figure 2: World coordinate system and predicted shortest distance.

2 HIERARCHICAL ACTION CONTROL METHOD

2.1 Nomenclature

Symbol	Quantity
T_i	prediction time
ρ_d	distance between the robot and the destination
ρ_{T_i}	predicted shortest distance between the robot and the obstacle
ρ_0	minimum of repulsive potential
$\mathbf{x}$	position vector of robot
$\mathbf{x}_d$	position vector of the destination
$\mathbf{x}_{o_j}$	position vector of object $_j$
$\mathbf{x}_{r,o_j}$	position vector of the obstacle O_j relative to the robot
$\mathbf{v}$	velocity vector of robot
$\mathbf{v}_{o_j}$	velocity vector of object $_j$
$\mathbf{v}_{r,o_j}$	velocity vector of the obstacle O_j relative to the robot
$U_j^{T_i}$	virtual potential about object $_j$ on each Time scale
$\mathbf{F}_j^{T_i}$	virtual force vector from $U_j^{T_i}$
i	index of each Time scale
j	index of object
x	x-axis
y	y-axis

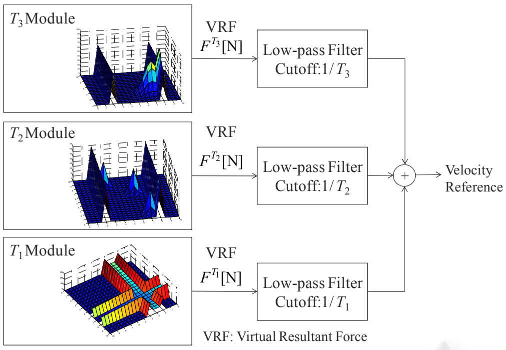


Figure 3: Output of each module and integration.

2.2 Design Approach

The module is a potential function with the prediction time as a parameter, and generates a potential field for each problem and virtual force on the robot is calculated. In this study, the proposed potential function was designed based on the repulsive potential reported by Khatib (Khatib, 1986).

$$U = U_{\mathbf{x}_d} + U_o \tag{1}$$

$$U_{\mathbf{x}_d} = k_a \rho_d \tag{2}$$

$$U_o = \sum U_j^{T_i} \tag{3}$$

$$U_j^{T_i} = \begin{cases} \eta T_i \left(\dfrac{1}{\rho_{T_i}} - \dfrac{1}{\left\| T_i \mathbf{v}_{r,o_j} \right\| + \rho_0} \right)^{\frac{1}{T_i}} & ,\rho_{T_i} \le \left\| T_i \mathbf{v}_{r,o_j} \right\| + \rho_0 \\ 0 & ,\rho_{T_i} > \left\| T_i \mathbf{v}_{r,o_j} \right\| + \rho_0 \end{cases} \tag{4}$$

where $\mathbf{x}_d$ is the destination position and $U_{\mathbf{x}_d}$ is an attractive potential field. In the proposed method, a repulsive potential function in consideration with prediction time T_i is used.

A force for the position $\mathbf{x}$ of the robot is derived from the following equation.

$$\mathbf{F}(\mathbf{x}) = -\frac{\partial U}{\partial \mathbf{x}} \tag{5}$$

where $\frac{\partial U}{\partial \mathbf{x}}$ denotes the partial derivation vector of the total virtual potential U. From Eqs. (2) and (5), the attractive force allowing the position $\mathbf{x}$ of the robot to reach the goal position $\mathbf{x}_d$ is as follows:

$$\mathbf{F}_{\mathbf{x}_d} = -k_a \frac{\partial \rho_d}{\partial \mathbf{x}} \tag{6}$$

From Eqs. (4) and (5), the repulsive force to the obstacle O_j are as follows:

$$\mathbf{F}_j^{T_i} = \begin{cases} \eta \left(\dfrac{1}{\rho_{T_i}} - \dfrac{1}{\left\| T_i \mathbf{v}_{r,o_j} \right\| + \rho_0} \right)^{\frac{1}{T_i}-1} \dfrac{1}{\rho_{T_i}^2} \dfrac{\partial \rho_{T_i}}{\partial \mathbf{x}} & , \rho_{T_i} \le \left\| T_i \mathbf{v}_{r,o_j} \right\| + \rho_0 \\ 0 & , \rho_{T_i} > \left\| T_i \mathbf{v}_{r,o_j} \right\| + \rho_0 \end{cases} \tag{7}$$

The command vector **F** of the robot is derived from the following equation.

$$\mathbf{F} = \mathbf{F}_{\mathbf{x}_d} + \mathbf{F}_o \tag{8}$$

When combining the virtual force derived from a potential field which is generated at each module, we consider the robot as a point mass. The velocity command with the same magnitude and direction is determined by combining the forces to the robot. In addition, the potential approach has a vibration problem caused by the magnitude of velocity and roughness of the control period. Thus, in the method, a low pass filter on each element of the virtual force output in each module is used to suppress such vibration as shown in Fig.3. It was confirmed that safe and effective motion is possible even in a situation where movement to the destination, avoiding moving obstacles, and emergency avoidance all coexist. In the simulations, each low pass filter uses the reciprocal of each prediction time as a cut-off frequency.

3 EXPERIMENTAL RESULTS

3.1 Experimental Environment

To verify the effectiveness of the proposed method in the actual situation, the experiments using the real robot were carried out. The robot size is L 0.55 × W 0.75 × H 1.25 m and the weight of the robot is about 60 kg. In order to recognize environment, the stereo camera and the stemma camera, the laser range finder and the ultrasonic sensor are loaded, but, in this research the robot recognizes environment making use of only the laser range finder. The velocity limit of the robot is 0.5m/s and the acceleration limit is 1.0m/s^2.

Figure 4 shows the experimental environment to verify the effectiveness of the proposed method to a static single obstacle. The initial position of the robot is (0 m, 0 m). The obstacle size is L 0.20 W 0.33 H 0.50 and its initial position is (-0.5 m, 3.0 m). Figure 7 shows the experimental environment. In this case, the moving obstacle bursts through the blind corner at the speed of 0.5 m/s when the robot comes close to the corner.

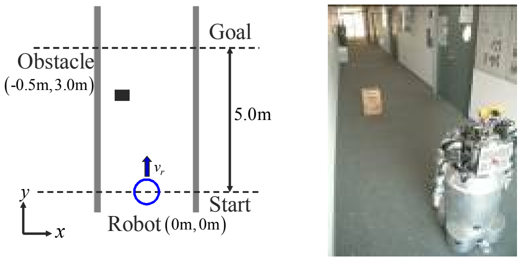
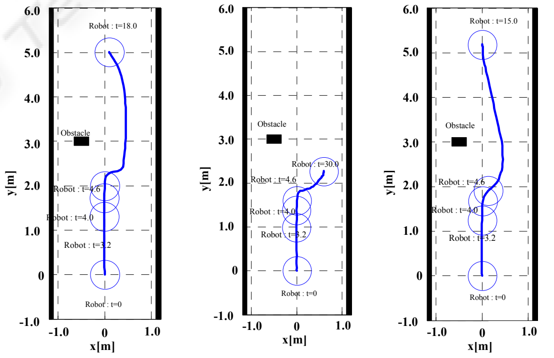


Figure 4: Experimental Environment.

3.2 Experimental Results

Figure 5 (a), (b) and (c) show the trajectory of the robot by using the Khatib ($\rho_0 = 0.8$, $\eta = 0.064$), the Khatib ($\rho_0 = 1.5$, $\eta = 0.064$) and the proposed method respectively.

From the result in Fig.5(a), it was confirmed that the robot comes close to the obstacle because the repulsive potential fields for the obstacle is small. Fig.5 (b) shows that the robot does not approach to the obstacle because the influence of the obstacle is large. In addition it receives the influence of repulsive force from the wall and thereby this can lead to the stable positioning of the robot before reaching its goal. On the other hand, it was confirmed in Fig.5(c) that the robot with the proposed method can reach its goal earlier than other methods without colliding with the obstacle.



(a) $\rho_0 = 0.8, \eta = 0.064$ (b) $\rho_0 = 1.5, \eta = 0.064$ (c) The proposed method.

Figure 5: Experimental Result.

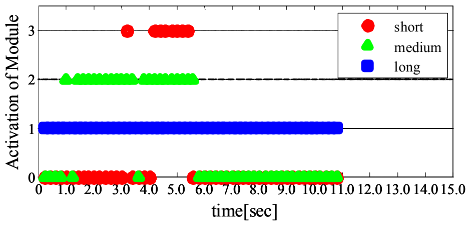


Figure 6: Time History of the Activation of Module.

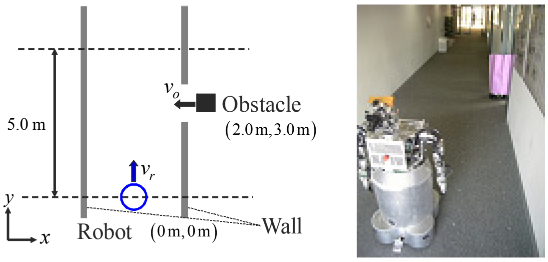
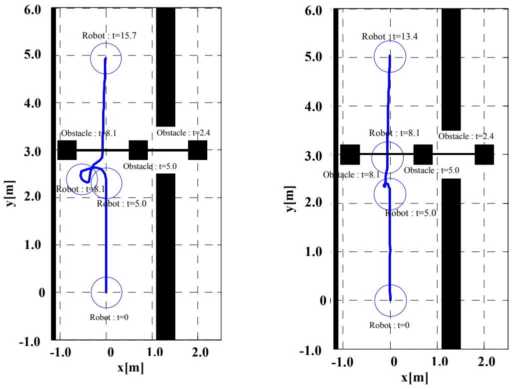
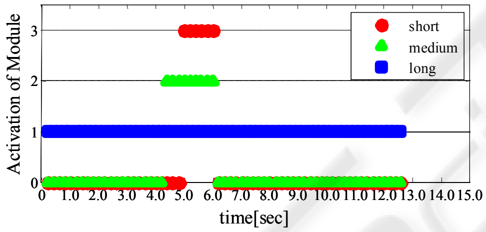


Figure 7: Experimental Environment.



(a) Khatib method (b) Proposed method



(c) Time History of the Activation of Module in the proposed method

Figure 8: Experimental Result.

Figure 8(a) and (b) show the trajectories of the robot and the moving obstacle by using the Khatib and the proposed method respectively. Figure 8(c) shows the time history of the activation of module in the proposed method. The robot can reach the goal without colliding with the obstacle. However, the robot moves in the direction of movement of the obstacle because the predicted information of the obstacle is not used. Thereby, the arrival time to the goal is longer than our method.

From the results in Fig.8 (b), it was confirmed that the robot recognizes the moving obstacle and then stops on the moment and starts the movement to the goal after the obstacle passes over. As shown in Fig.8(c), the robot can move without colliding against the moving obstacle by acting on the emergency avoidance module simultaneously with the collision avoidance module around 5.0sec which it approaches to the robot.

4 CONCLUSIONS

This study proposed the hierarchical action control method for an autonomous omni-directional mobile robot to realize the safe and effective movement. In the method, the module with different prediction time processes in parallel, and the command velocity to the robot is decided by integrating them. As for each module, the selection condition is different according to relative position and velocity about the robot and the obstacle.

From the results of the numerical simulations and the experiments, it was confirmed that the robot can reach the goal efficiently without colliding with both the static and the moving obstacles by using the estimated information of them.

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