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Simple Obstacle Avoidance for a Mobile Robot Moving through Via Points*

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***Abstract*— This study presents simple obstacle avoidance of a mobile robot that moves through via points in a dynamic environment in which obstacles move. This proposed system consists of two controllers, a reference controller and a PI-controller. The reference controller generates a robot motion reference trajectory in reaching goals and avoiding obstacles by referring sensor information in real time trajectory and the PI-controller moves robot to follow the reference trajectory. Computer simulation was performed to test the effectiveness of proposed method and then extended to experimental tests.**

I. INTRODUCTION

Robot navigation is the ability to move the robot safely toward goals using its knowledge on environment [1][2]. Obstacle avoidance is one of the main functions required in autonomous robot navigation [3][4]. The effectiveness of obstacle avoidance will be improved by fusing some sensors simultaneously instead of using only a single sensor.

Sensor fusion is a combination of sensory data that has an inherent redundancy and may provide robust recognition of robot working environment [5-7]. The applied sensors in a mobile robot can give partial knowledge on its environment and goal position(s) to encompass the robot reaching its goal position(s) as efficiently and reliable as possible [8].

One of the application of mobile robot is a service robot [9-13] because it is expected to work in a dynamic environment such as a restaurant environment [14]. The application of mobile robot as a service robot can be semi automatic [15] or fully automomatic [16].

This study deals with collision avoidance control for a service mobile robot moving in a dynamic environment consisting of moving obstacles. A method for sensor fusion is presented to achieve the motion in a dynamic environment. The proposed method combines the information obtained by several proximity sensors and an image sensor. The robot controllers consist of a reference controller and a PI controller. The reference controller generates a robot motion trajectory by referring sensor information in real-time, and the PI controller moves the robots to follow the generated motion trajectory. Various simulation and experimental results, which assume static and dynamic objects in the environment, demonstrate the effectiveness of the proposed design.

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II. MOBILE ROBOT DYNAMICS AND CONTROLLER DESIGN

A. Robot Dynamics

This study considers a typical two wheeled differential-drive mobile robot as shown in Fig. 1.

$$I\ddot{\phi} = (D_r - D_l)\,l \tag{1}$$

$$M\dot{v} = D_r + D_l \tag{2}$$

where the notations for Fig. 1, (1) and (2) are given below:

I	moment of inertia of the robot around the center of gravity
M	mass of the robot
D_r, D_l	driving forces for the right and left wheels
l	half width of the robot
$\ddot{\phi}, \dot{v}$	angular and translational acceleration of the robot

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B. Reference Controller Design

This study applies a reference controller and a PI controller for the collision avoidance as shown in Fig. 2. The reference controller generates the reference trajectory for robot, and the PI controller moves the robot to follow the reference trajectory.

Environmental information needed to create the reference trajectory is provided by fusing multiple sensors; a Kinect

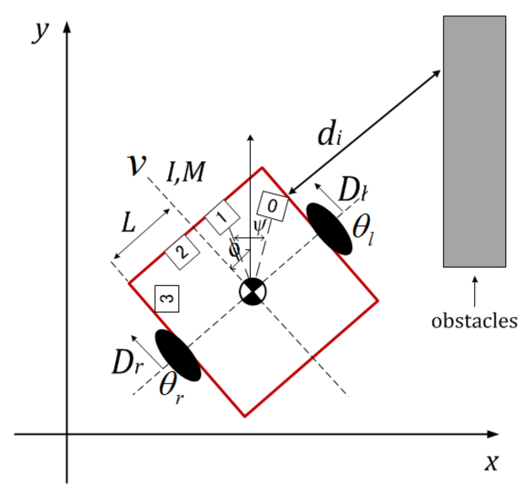


Fig. 1. Two-Wheeled Mobile Robot

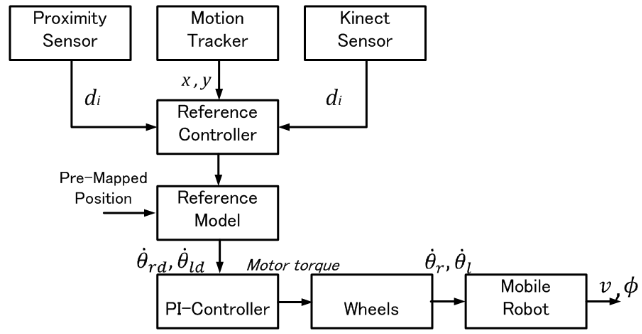


Fig. 2. Block Diagram of Proposed Method

sensor, four proximity sensors and an motion tracking system. We assume that the motion tracking system provides the position of a human to be tracked by the robot. Markers are attached to the human and obstacles. Motion tracker is installed on a robot that will look for markers in real time.

We consider (1) and (2) to derive the following reference model to generate the reference trajectory for a robot.

$$I\ddot{\phi}_d(t) + C\dot{\phi}_d(t) = \tau_u + \tau_1 + \tau_2 \tag{3}$$

$$M\dot{v}_d(t) + Cv\phi_d(t) = F_u + F_1 + F_2 \tag{4}$$

where

C	virtual damping coefficient for increasing the stability
$\dot{\theta}_{rd}, \dot{\theta}_{ld}$	reference angular velocity of the right and left wheels
$\dot{\phi}_d, v_d$	desired angular and translational velocity of the robots generated by a reference controller
τ_u, F_u	torque and force applied to the robot to move to the tracked marker
τ_i, F_i	torque and force applied to the robot to follow the tracked marker (i=1,2)

The reference trajectory is created by adding the virtual torque and force (τ_1, τ_2, F_1 and F_2) to the dynamics of mobile robots in (3) and (4). The virtual torque and force are calculated by considering the fused data input from the Kinect sensor, proximity sensors, and motion tracking system as shown in Fig.2.

Torque τ_1 and τ_2 is designed for collision avoidance and keeping the robot parallel to the virtual wall of the passages, respectively. The force F_1 gives deceleration effect according to the distance of the robot to obstacles, and F_2 is used to give deceleration effect according to the approaching speed of dynamic obstacles. These four parameters are used to adjust the magnitude of virtual external force/torque calculated below:

$$\tau_1 = \operatorname{sgn}(v)\left(\sum_{i=0,3} s(d_i) - \sum_{i=1,2} s(d_i)\right) \tag{5}$$

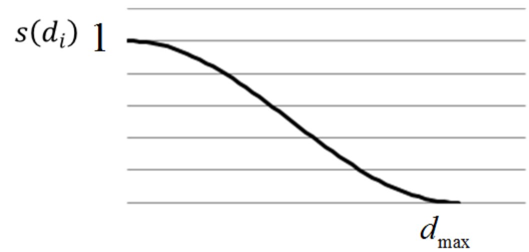


Fig. 3. The Shape Function of Distance

$$\tau_2 = \alpha_2\left(\sum_{i=0,3} s(d_i) - \sum_{i=1,2} s(d_i)\right) \tag{6}$$

$$F_1 = \beta_1\left(\sum_{i=0,3} s(d_i) + \sum_{i=1,2} s(d_i)\right) \tag{7}$$

$$F_2 = \beta_2\left(\sum_{i=0,3} \min(\dot{d}_i, 0) + \sum_{i=1,2} \min(\dot{d}_i, 0)\right) \tag{8}$$

where

$\operatorname{sgn}(v)$	the sign function of translational velocity of the robot
α_i, β_i	adjustable constants to provide the effective collision avoidance (i=1,2)
$\dot{d}_i$	time derivative of distance d_i to obstacles, which corresponds to the approaching robot speed to obstacles
$s(d_i)$	shape function represents the relationship between the virtual external force and the distance to obstacle, the shape function is 0 when $d_i \geq d_{\max}$, and the shape function is 1 when $d_i = 0$
$d_{\max}$	maximum distance that can be measured by the sensor

The shape function of the distance in Fig. 3 is designed as follows:

$$\begin{cases} s(d_i) = 1, \text{if } d_i < \tilde{d} \\ s(d_i) = \frac{1}{a}\left[\exp\left\{-\frac{(d_i - \tilde{d})^2}{2\sigma^2}\right\} - b\right], \text{if } d_i > \tilde{d} \end{cases} \tag{9}$$

$$b = \exp\left\{-\frac{(d_{\max} - \tilde{d})^2}{2\sigma^2}\right\}, a = 1 - b \tag{10}$$

where σ and $\tilde{d}$ are the design parameters for defining the shape function of the virtual external force

The virtual external torque and force increase as the distance to the obstacle is smaller. The virtual external force will be zero when the distance of robot from the obstacle is greater than $d_{\max}$, which is a design parameter according to the sensor specification.

C. PI Controller Design

The PI control is employed to move the robot to follow the desired trajectory. In this study, the PI control is employed by calculating the difference of the desired velocity and the actual velocity. The PI control equations applied in this study is given bellow:

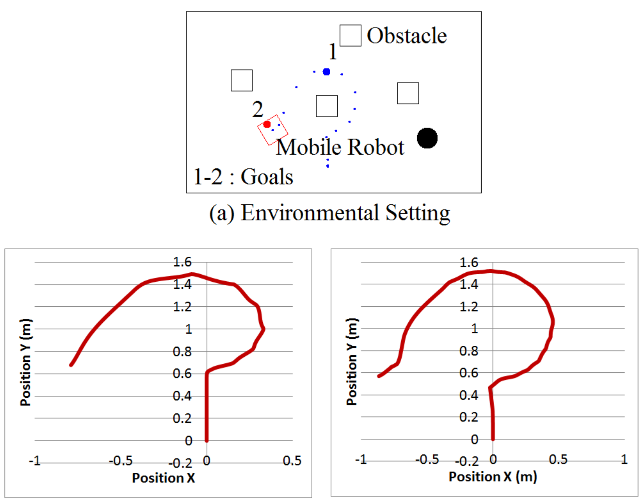
$$\tau_{mr} = K_P\left(\dot{\theta}_{rd} - \dot{\theta}_r\right) + K_I \int \left(\dot{\theta}_{r,u} - \dot{\theta}_r\right) \tag{11}$$

$$\tau_{ml} = K_P\left(\dot{\theta}_{ld} - \dot{\theta}_l\right) + K_I \int \left(\dot{\theta}_{l,u} - \dot{\theta}_l\right) \tag{12}$$

where τ_{mr} and τ_{ml} are motor torque for the right and left wheel respectively, K_P is the proportional gain and K_I is the integral gain.

III. EXPERIMENTAL RESULTS

The experiment in this paper is only for verifying the ability of robot to move via points while avoiding obstacles; the static and dynamic ones. The mobile robot applied in this research has four IR-proximity sensors and Kinect Sensor. The algorithm and hardware design are kept simple so that the proposed control can be applied to a variety of service robots.



(a) Environmental Setting

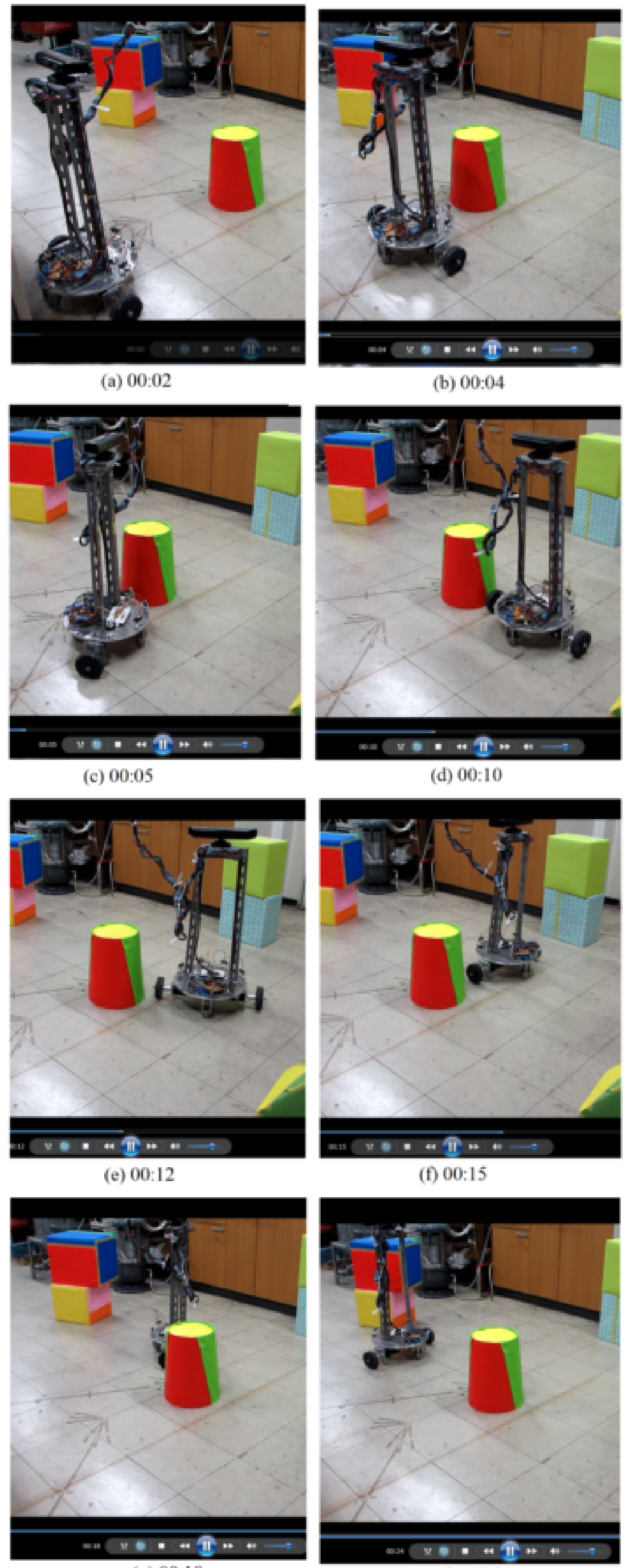
(b) Simulation Result

(c) Experimental Result

Fig. 4. Two Via Points Case

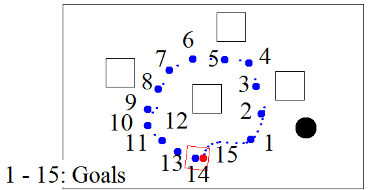
Figures 4 and 6 are the comparison of robot position and orientation of simulation results and experimental results, (a) is the environmental setting, and via points are indicated by numbers, (b) is the simulation result and (c) is the experimental one. Figures. 5 and 7 are the video captures results of Figs. 4 and 6, respectively which show the robot can reach all via points while avoiding obstacles.

The application of Kinect Sensor is to know the existance of dynamic obstacle (passing human). In the current application, when 'seeing' human and human reaches the minimum allowed distance, robot stops. Kinect sensor is also used for the obstacles position's is higher or undetectable by IR-proximity sensor.

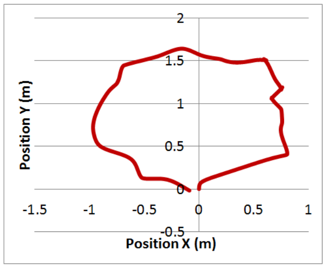


(a) 00:02 (b) 00:04 (c) 00:05 (d) 00:10 (e) 00:12 (f) 00:15 (g) 00:18 (h) 00:24

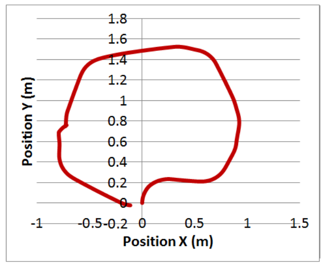
Fig. 5. Video Captures for Results in Fig. 4



(a) Environmental Setting



(b) Simulation Result



(c) Experimental Result

Fig. 6. Fifthteen Via Points Case

The results obtained from this preliminary study will be used to develop as a service robot in human living environment.

IV. CONCLUSIONS

This paper presents simple obstacle avoidance for a mobile robot moving through via points. The future application of this robot is a service mobile robot for human living environment. Simulation results show that the robot moves via points smoothly with two different via point settings. Experimental system was constructed and the effectiveness of the proposed system was confirmed.

(a) 00:01

(b) 00:06

(c) 00:09

(d) 00:13

(e) 00:20

(f) 00:35

Fig. 7. Video Captures fo Results in Fig. 6

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