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Obstacle Avoidance Control of Indoor Patrol Robots Using Image-Sensing Techniques

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Abstract: The wheel robot is one of the very popular research topics. Applications of wheel robots include security, searching and rescue tasks in the indoor environment. In this paper, the image-sensing techniques, including an image system and a laser range finder, are used for obstacle avoidance and environment identification. The image system could provide 2D information of indoor environment, and the depth information is provided from the laser range finder. Therefore the 3D environment can be reconstructed and the position of the robot can be obtained. The moving paths of robot are automatically real-time regulated with 3D environment information. Moreover, a monitoring station is proposed for supervising the robot. The display of the station includes the laser range finder display and real-time video. In the experimental results, the 3D environment information is displayed on station and the robot can indeed avoid the obstacles in the indoor environment automatically.

Keywords: Patrol robots, Image processing, Obstacle avoidance.

1. INTRODUCTION

The developments of the robots are generally divided into two categories. They are service robots and industrial robots. In 90's, the mechatronic systems are extensively used for manufacturing and precision industry. In recent years, this technology is applied to robot systems. After years of researches, the functions of service robots are more and more comprehensive. For example, the home cleaning robots of Cyberhuis Company [1] are one kind of the service robots. Another application of wheel robots is security robot. Since the security robot has to take multiple tasks, the control of the security robot has to be more intelligent.

Chien et al [2] proposed the system architecture of security robot with multiple sensors. Obviously, designing functions of positioning and obstacle avoidance of a security robot is a difficult and important research problem. To achieve better performance, the dynamic of a robot system, which has been discussed in [3], [4] and [5], has to be considered. Yun et al described the wheeled mobile robot dynamic with physical analysis. The robot system used in this paper is s wheeled mobile robot. In this paper, we will propose a method for an indoor patrol robot to avoid obstacles automatically, based on the mobile robot model.

The planning of automatic obstacle avoidance includes "*Searching Mode*" and "*Obstacle Avoidance Mode*". The feedback of sensors will be the mode switching condition. From the experimental results, we will verify that the proposed method can achieve not only the obstacle avoidance but also basic navigation of robots. Moreover, the robot has been announced in robot competition conducted by SKS Co., Ltd., Taiwan, 2011.

2. OBSTACLE AVOIDANCE METHOD OF THE ROBOT

2.1. Modeling of robot system

Consider the mobile robot system with two fixed wheels as illustrated in Fig. 1. We define two coordinates, which are the inertial coordinate and the robot coordinate, for the robot system. In addition, the nonholonomic motion constraints [6] [7] are

$$\dot{X}_{cp}\cos\theta + \dot{Y}_{cp}\sin\theta - k\dot{\theta} - r\dot{\omega} = 0 \quad (1)$$

$$\dot{X}_{cp}\sin\theta - \dot{Y}_{cp}\cos\theta = 0 \quad (2)$$

where $Q(X_{cp}, Y_{cp})$ is the mass center of the robot, and ω is the wheel speed.

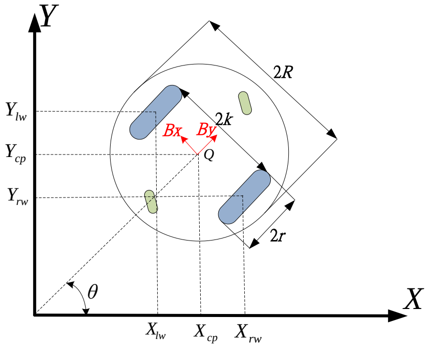


Fig. 1. The coordinate definitions of the robot.

Based on the Appell Equation, the dynamic equation of the robot system is

$$A(y)\ddot{y} + C(y,\dot{y})\dot{y} = B(y)\tau \quad (3)$$

where τ is the torque of the wheel, and

$$\begin{cases} \dot{y} = \mathrm{u} = \begin{bmatrix} \dot{\omega} & \dot{\theta} \end{bmatrix}^T \\ A(y) = \begin{bmatrix} \eta M_2 & M_1 \\ M_2 & \eta M_1 \end{bmatrix} \\ C(y,\dot{y}) = \begin{bmatrix} m_b r d_r \dot{\theta} & 0 \\ 0 & -m_b r d_r \dot{\theta} \end{bmatrix} \\ B(y) = \begin{bmatrix} 0 & 2\eta \\ 1 & 1 \end{bmatrix} \end{cases} \quad (4)$$

Moreover, in (4), M_1 and M_2 are

$$M_1 = m_b(d_r^2 + k^2) + U_p + 4m_w k^2 + 2U_w + 8\eta^2 U_w \quad (5)$$

$$M_2 = m_b r^2 + 2m_w r^2 + 4U_w \quad (6)$$

and the parameters in (4)-(6) are

$$U_p = \frac{1}{3} m_b \left(2R^2\right) \quad (7)$$

$$U_w = \frac{1}{2} m_w \left(r^2\right) \quad (8)$$

$$\eta = \frac{k}{r} \quad (9)$$

where U_p and U_w are the moments of inertia of the robot and wheels, respectively. The m_b and m_w are the mass of robot and wheels, respectively.

Equation (3) can be transformed into the state equation

$$\dot{\mathrm{x}} = \mathrm{f}(\mathrm{x}) + \mathrm{H}(\mathrm{x})\tau \quad (10)$$

where

$$\mathrm{x} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \end{bmatrix}^T = \begin{bmatrix} \omega & \dot{\omega} & \theta & \dot{\theta} \end{bmatrix}^T, \quad (11)$$

$$\mathrm{f}(\mathrm{x}) = \begin{bmatrix} x_2 \\ -\eta\kappa J_s x_2 x_4 - \kappa J_v x_4^2 \\ x_4 \\ J_s \kappa\left(x_2 x_4 + \eta x_4^2\right) \end{bmatrix} \quad (12)$$

$$\mathrm{H}(\mathrm{x}) = \begin{bmatrix} 0 & 0 \\ -J_v & 2\eta^2 J_s - J_v \\ 0 & 0 \\ \eta J_s & -\eta J_s \end{bmatrix} \quad (13)$$

$$J_s = \frac{1}{\eta^2 M_2 - M_1} \quad (14)$$

$$J_v = \frac{M_1}{M_2} J_s, \kappa = m_b r d_r \quad (15)$$

Therefore the dynamic model of the robot system could be described by (10).

2.2. Image processing and image guiding method

Since it is possible that there is more than one room that the robot has to patrol, the area of door or corridor has to be computed. In this case, the image guiding method can be one solution to compute the area of doors or corridors and then label them. The image guiding method is illustrated as Fig. 2.

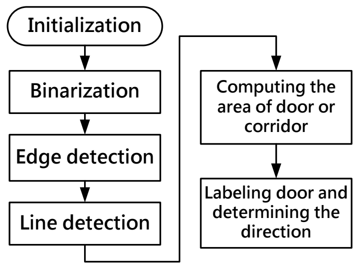
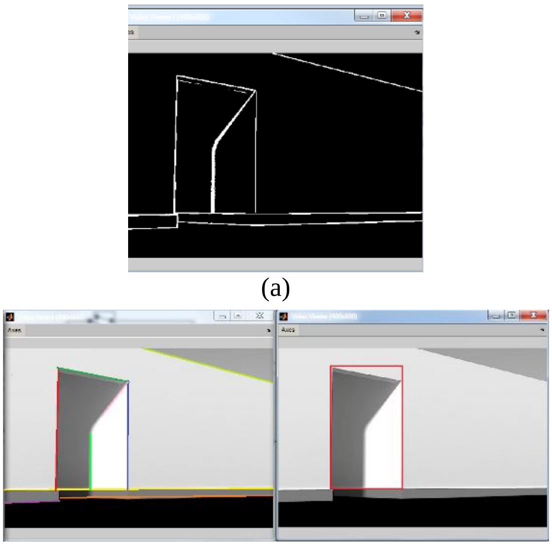


Fig. 2. Flowchart of the image guiding method.

There are three things that have to be considered in designing the algorithm. The first is the length and width of the room. The second is the dynamic restrictions of the robot. Finally, in order to prevent the collision with any obstacle near to the robot unexpectedly, the urgent distance is necessary. When there is any object entering the urgent area, the robot should stop immediately.

Hence, at first of the algorithm, the edges of the wall are detected [8] and the lines are extracted with Hough transform [9]. Then we compute the area of doors or corridors with information feedback from the laser range finder and the image information. The final step is labeling the door and determining the moving direction. The robot will turn toward the door with the image guiding method. Fig. 3 is a simulation of door labeling with the computer graphics (CG). Fig. 4 shows the real-time edge and line detecting results.

Since the robot may move in an unknown environment, two mission modes "***Searching Mode***" and "***Obstacle Avoidance Mode***", which constitute the automatic obstacle



(a) (b) (c)

Fig.3. Simulation of door labeling with the computer graphics (CG). (a) The detected edge. (b) The line detection. (c) The door labeling.

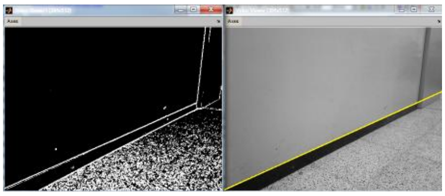


Fig.4. The real-time edge and line detecting results.

avoidance method, are defined in our setup. Two warning areas are defined by the distance from the robot for touching off the robot to run "*Searching Mode*" or "*Obstacle Avoidance Mode*".

Define an inner warning area W_2 which is the area with distance to the robot less than w_2, and an outer warning area W_1 which is the area with distance to the robot greater than w_2 but less than w_1. Base on these two warning area, there are three possible cases. Case 1 is the case if there is no obstacle located in region W_1. Case 2 is the situation that there are obstacles located in W_1. Case 3 occurs when any obstacle is located in W_2. The corresponding actions of the robot in each case are summarized in Table 1. The automatic obstacle avoidance method is illustrated as Fig. 5.

Table 1. The corresponding actions of robot in Case1~3.

Case	Robot actions
1	Running in "***Searching Mode***".
2	Warning and computing the distances of obstacles.
3	Running in "***Obstacle Avoidance Mode***".

All the orientation parameters are obtained by laser range finder in one scanning. The distance between the each edge points are

$$L_j = \sqrt{(x_j - x_{j+1})^2 + (y_j - y_{j+1})^2}, \quad j = 1,2,\cdots k. \quad (16)$$

All possible passages are defined as "Candidate Passages". In order to select the correct passage, we further define the requirements of "Final Passage" and "Spurious Passages" are

$$\begin{cases} L_j \geq 2R + u, & \text{Final Passage} \\ \text{Otherwise}, & \text{Spurious Passage} \end{cases}. \quad (17)$$

where R is the radius of the robot chassis and u is the urgent distance. Moreover the "Spurious Passages" will be regarded as obstacles. The automatic obstacle avoidance method is illustrated as Fig. 6.

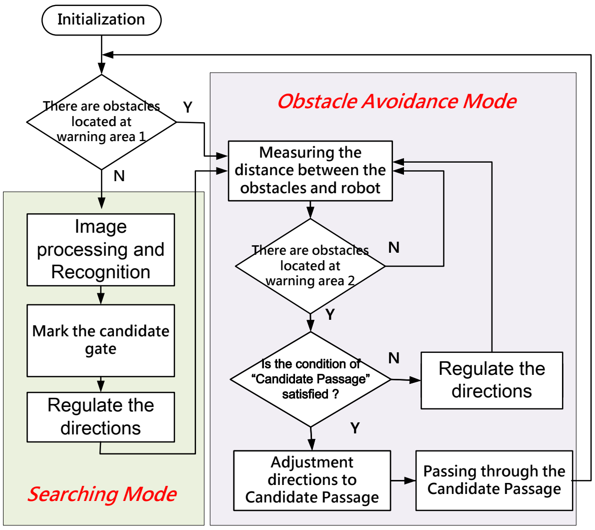


Fig.5. The automatic obstacle avoidance method.

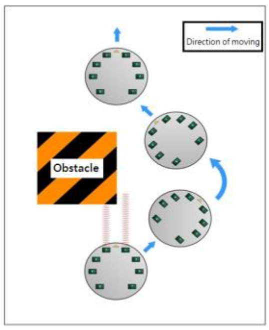


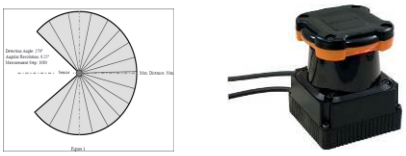
Fig.6. "*Obstacle avoidance mode*" of the robot.

3. SIMULATION RESULTS

There are two layers in the platform of the robot for the paper. The platform is constituted with aluminum panels. The maximum payload of the robot is 8 kg. The diameter and height of the mobile robot are 0.4 m and 0.44 m, respectively. The wheels are directly driven by the motors.

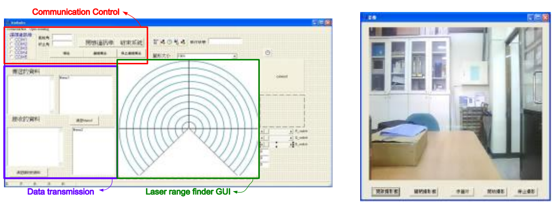
The design of the chassis is differential drive moving platform. The scanning laser finder used for the robot is UTM-30LX (Hokuyo Automatic Co., Ltd., Osaka, Japan), as shown in Fig. 7. The scanning angle and the guaranteed detection range are 0°~270° and 30 m, respectively. The interface of the robot system and the real-time image obtained from the robot are shown in Fig. 8.

Considering the experimental environment, the area W_1 is defined as the distance less than 3 m and the area W_2 is defined as the distance between 3 m and 0.75 m. The urgent distance is defined as 0.15 m. A tortuous corridor is designed for testing our method. Fig. 9 (a) (b) show the robot passing through the tortuous corridor successfully with "*Obstacle Avoidance Mode*". In addition, this testing example shows the obstacle avoidance performance of robot.



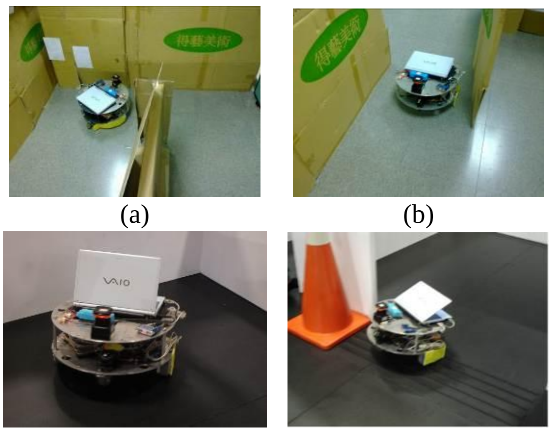
(a) (b)

Fig. 7. (a) The scanning range. (b) Appearance of UTM-30LX.



(a) (b)

Fig. 8. (a) The interface of the scanning laser finder. (b) The real-time image.



(c) (d)

Fig. 9. The robot passing through a corridor and patrolling in the room.

The next testing example is in the site of the SKS Company Robot Competition. In Fig. 9 (c) (d), the robot is patrolling in the room automatically. The algorithm can recognize the door and guide the robot passing through the door.

4. CONCLUSION

In this paper, we proposed a simple method for achieving autonomous obstacle avoidance and basic navigation of robot. Based on the feedback of the camera and laser range finder, the robot is more intelligent and sensitive. Moreover, the proposed algorithm is simple, therefore that could be used for real-time robot obstacle avoidance. In experimental results, we have shown that a robot with our algorithm could not only search rooms automatically but also pass through the narrow gallery in flexibility. It shows that the performance of the robot will be good for most indoor environments.

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