Local Obstacle Avoidance with Reliable Goal Acquisition for Mobile Robots

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Summary. In this paper, we propose a method of obstacle avoidance and goal acquisition for mobile robots in unknown environments. We have modified the navigation method, Vector Field Histogram(VFH) by Borenstien *et al.*. Our method, Sensor Based Vector Field Histogram(SBVFH), designs for more sensor-reactive method. Our method concerns the situation that several mobile robots travelling in the environment. The mobile robot is goal-directed while trying to avoid static and moving obstacles. The results of simulation and experiment show that the algorithm is efficient with relatively cheap sensors.

Key words:mobile robot, obstacle avoidance, navigation

1 Introduction

Obstacle avoidance is one of fundamental key to successful applications of autonomous mobile robot systems. Obstacle avoidance means detection of obstacle and stop or change direction of the mobile robot in order to avoid the collision. Also there are sophisticated algorithms , which enable the robot to avoid the obstacle and proceed toward its goal. In this paper, we focus at the problem of obstacle avoidance and goal acquisition for mobile robots operating in unknown or partially known environments. The problem has been studied in previous works[1],[2],[3], [4], [5].

Our method is the extended version of Vector Field Histogram(VFH) method[1]. Our method utilizes raw sonar sensor readings to rapidly avoid obstacles. The method is called Sensor Based Vector Field Histogram(SBVFH). Our approach concerns the situations that there are moving obstacles (e.g. other mobile robots) in the environments. The method navigates a mobile robot safely, even with a noisy sensors(such as sonar sensor). The mobile robot is goal-directed while trying to avoid obstacles. The mobile robots is able to avoid collision with each other. Our mobile robots can communicate through wireless LAN. However, the mobile robots are not use the communicated information to plan priority for each mobile robot to move. The goal acquisition is done using map, which is built as the mobile robot moving. Our method works by choosing velocity and direction that satisfies all constraints and maximizes an objective function. Constraints derive from physical limitations of the mobile robot, and from the sensor readings that indicate the presence of obstacles that also be used to build map. Our method also interprets the sensor readings to obtain acceleration and deceleration in the selected approaching direction. The deceleration of the mobile robot prevents the deadlock situation when encounter other mobile robots.

To achieve real-time performance, our method simply searchs approximated direction to goal in the map. Several simple extensions make the basic method more robust to sensor noise and reduce the possibility of the robot getting stuck. The experiments on our actual mobile robot demonstrate that our method provides safe and reliable navigation for indoor mobile robot systems.

2 Obstacle Representation

To represent the obstacles in an environment, the mobile robot could build a model of the environment from the sensor readings. In our research, an occupancy based model is used for representation of the model[8],[6],[9]. The model is especially suited to path planning, navigation and obstacle avoidance because it explicitly models free space.

In occupancy based model, the mobile robot's environment is represented by a two-dimensional array of square occupancy grid. The sensor readings are fused into the model using the Dempster-Shafer inference rule[9]. The model becomes map, which represents the environment of the mobile robot. The sensor model of the sonar sensors equipped on our mobile robot is shown in Fig. 1. The assumption made from the sensor reading is that the echo is generated somewhere on an arc at range R, within the sensor beam $\pm\beta$.

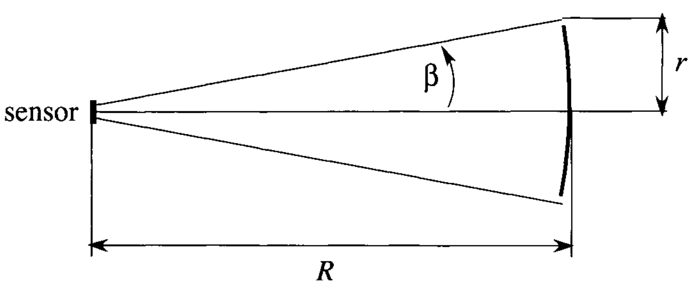

Fig. 1. Sonar sensor model

3 Sensor-Based Vector Field Histogram Algorithm

Our method is inspired by Vector Field Histogram(VFH)[1] method originally developed by Borenstien and Koren for real-time local obstacle avoidance. Our method utilizes histogram directly from raw sonar sensor readings. The traversibility to the goal is evaluated using occupancy map[6].

Our mobile robot is omnidirectional mobile robot. The mobile robot was equipped with k sonar sensors. The sensing area of sensor $1, 2, \ldots, k$ is shown in Fig. 2a. The n sector of candidate moving direction for the mobile robot is depicted in Fig. 2b. Our mobile robot exploits the raw sensor readings to avoid obstacles while determines the velocity to approach it goal.

3.1 Sensor Reading Interpretation

The sensor reading is evaluated to calculate traversibility for each sector. The value of traversibility is called Sector Value(SV). At each sampling cycle, the SV is classified into 4 cases. Each case indicates the possibility of the mobile robot to collide with obstacles as follows.

- S_1 : no collision possibility at maximum speed in the direction
- S_2 : deceleration is needed to avoid the collision if the obstacle is moving
- S_3 : deceleration can avoid only a static obstacle
- S_4 : cannot approach at any speed in the direction

For each case, following condition is obtained respectively.

- if($\tau_H \leq d$) then S_1
- if($\tau_M \leq d \leq \tau_H$) then S_2
- if($\tau_L \leq d \leq \tau_M$) then S_3
- if($d \leq \tau_L$) then S_4

Here, d is the distance from sensor reading and τ is the distance indicates the borderline in each case of collision possibility. Therefore, each value of the borderline can be defined as

$$\tau_H = 2 \cdot V_{max} \cdot \Delta t + d_{safe} \tag{1}$$

$$\tau_M = (\rho + 1) \cdot V_{max} \cdot \Delta t + d_{safe} \tag{2}$$

$$\tau_L = \rho \cdot V_{max} \cdot \Delta t + d_{safe} \tag{3}$$

Here, V_{max} is the maximum speed of the mobile robot, Δt is the sampling rate of the sensor readings, ρ is the deceleration rate of the mobile robot and d_{safe} is the allowable distance from the mobile robot to obstacles. Collision possibility of each SV is determined using configuration obstacles[7]. Fig. 3 shows the configuration obstacles have influence on the sectors.

The priority of S_1 is higher than S_2, S_2 than S_3 and S_3 than S_4 at the sectors that was effected by multiple sensor readings.

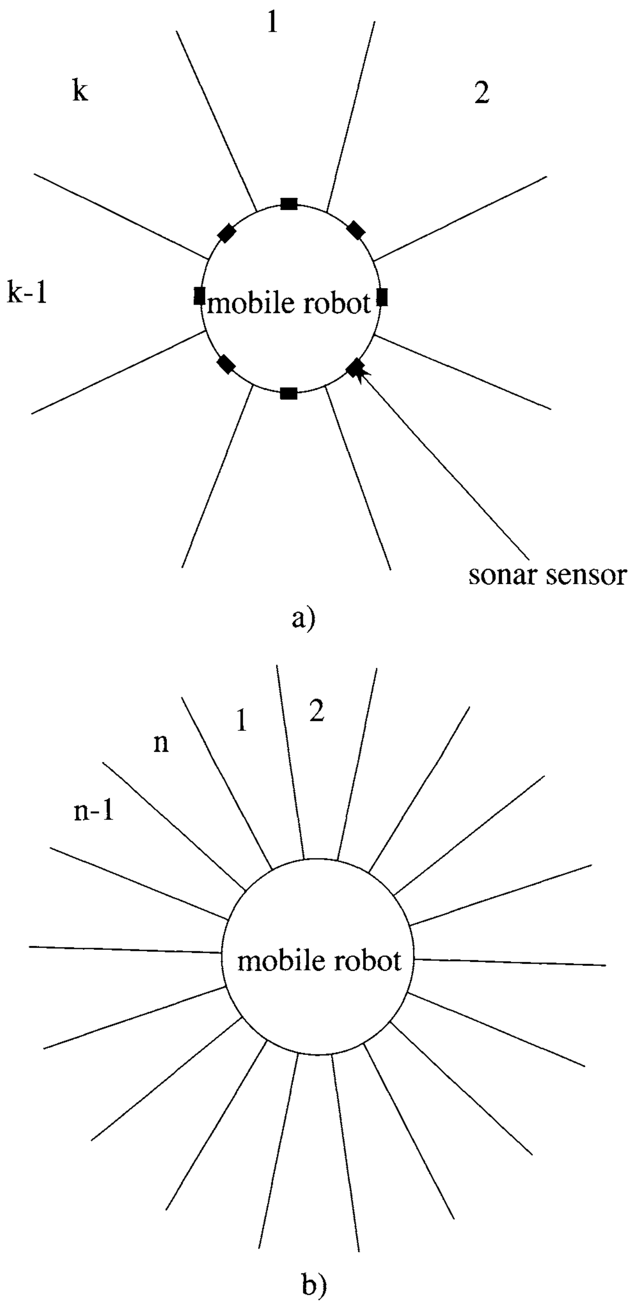

Fig. 2. Sensing area (a) and Sector (b)

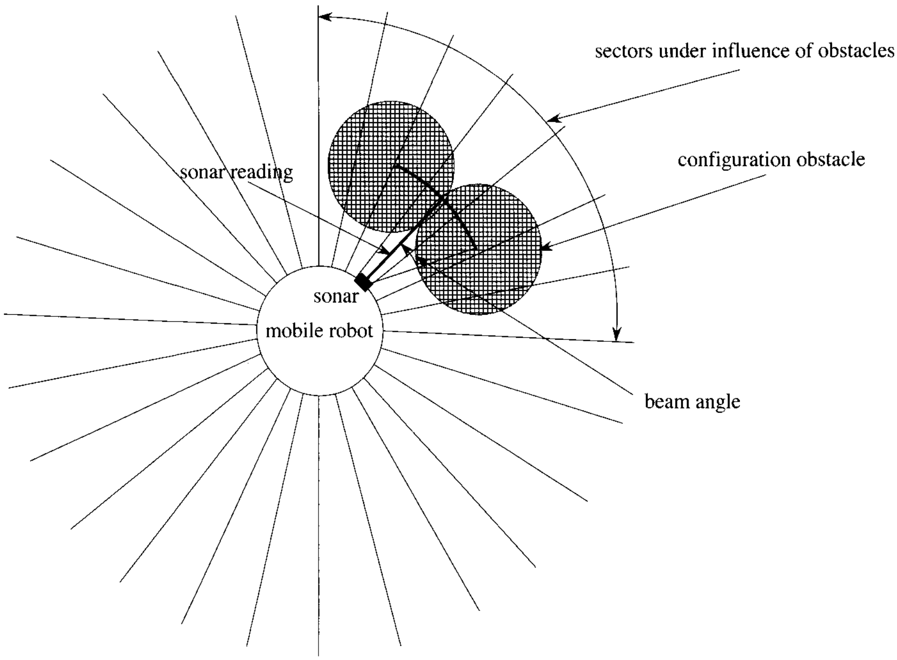

Fig. 3. Configuration obstacles over the sectors

3.2 Constructing Histogram

The polar histogram is built from SV of each sector as shown in Fig. 4. The directions($\theta_1, \theta_2, \ldots, \theta_n$) in the polar histogram is corresponding to the momentary position of the mobile robot. H_k shows the proper action that the mobile robot should take during traverse to the direction. H_k for each direction is derived from the condition in Section 3.1. H_k indicates the following actions.

- $H_k = 0$: acceleration
- $H_k = 1$: maintain speed
- $H_k = 2$: deceleration
- $H_k = 3$: not traversable

The mobile robot has to choose the approaching direction from the directions, which histogram are $H_k < 3$.

3.3 Goal Acquisition and Navigation Cost Factor

In the next stage, our algorithm has to compute the actual approaching direction that leads the mobile robot to the goal. The occupancy based map of the environment is used here to determine the proper approaching direction for the mobile robot. The direction to goal α is determine using map information. An instance of the navigation function family of algorithms [7]

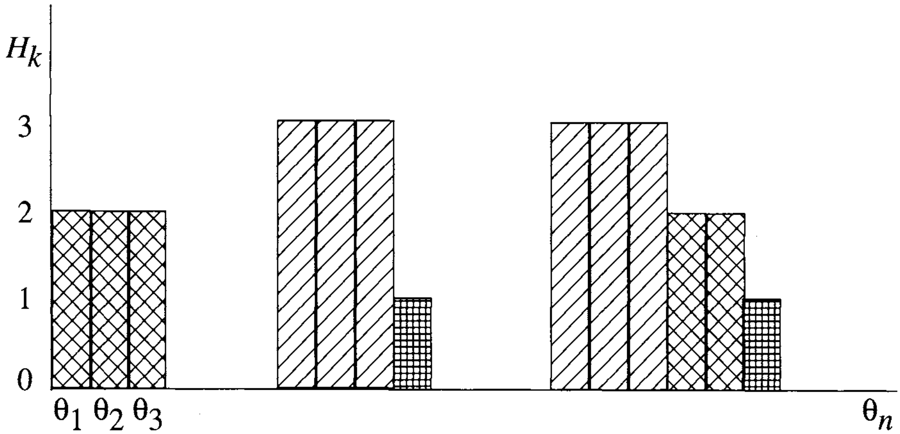

Fig. 4. Graph of histogram from the SV of each sector

is used to calculated the cost of driving from the current position to the proposed destinations based on the information in the occupancy grid map. α is the approximated direction, which has the lowest cost to the goal(Fig. ??). The driving cost is calculated from goal point to the current position of the mobile robot. By backtracking the search in the limited number of step the approximated direction to goal position can be obtained.

The navigation direction is evaluated from function $f(\zeta)$.

$$f(\zeta) = |\zeta - \alpha| + |\zeta - \beta| + \gamma \tag{4}$$

Here, ζ is the desired direction that should minimize $f(\zeta)$. α is the direction to goal. β is the current direction of the mobile robot and γ is the deceleration rate randomly selected from 0.3, 0.4, 0.5, 0.6, and 0.7. Randomly selecting deceleration rate also prevent the mobile robots to be trapped in the deadlock situations.

4 Simulation and Experiment

We have performed simulations to validate the SBVFH method. Our method is implemented in Player/Stage simulator[10],[11],[12]. The simulation is run on 750[MHz] PC. Fig. 5 shows the navigation and mapping simulation of a mobile robot. The mobile robot is approximated to be a circle with 230[mm] in radius. The mobile robot is equipped with 8 sonar sensors. The maximum range of the sonar sensor is 2[m]. The number of sector is 24. The parameters of SBVFH are as follows:

- $V_{max} = 0.5$[m/s]
- $\Delta t = 0.1$[s]

- $d_{safe} = 0.3$[m]
- $\rho = 0.5$[m/s^2]

The sampling time Δt 0.1[s] is the value measured from the simulation. This sampling rate can be told to be fast enough for actual mobile robot to perform in actual environment.

The experiment with actual mobile robot has been done using two omnidirectional mobile robots. The drive mechanism of both mobile robot is developed by RIKEN [13]. The on-board processor of the mobile robot is the industrial 650[MHz] computer. Each mobile robot is equipped with 8 sonar sensors. The maximum range of the sonar sensor is 3[m] and the beam angle is ±45[deg]. The mobile robots maintain their odometry using encoders. The motion controller of the mobile robot receives desired velocities from the processor and sends velocity command to external PID controllers.

In the experiment, the mobile robots have a difficulty to accurately detect each other when encounter in close range. The difficulty happens due to the direct hit of another mobile robot's sonar sensor. To avoid the fault detection, in the experiment, the mobile robot broadcast their position through wireless LAN. The broadcasted position information is used only when mobile robots are too close to each other. The position information is used to recover the fault sensor readings.

The goal of the mobile robots in the experiment is to switch their position. There is a static obstacle in the middle of the environment. Fig. 6 shows the experiment of two actual mobile robots. In Fig. 6c, the mobile robot No.1 avoids the static obstacle and meet the mobile robot No.2. The mobile robot No.2 detects No.1 and changes direction to the other side of the environment. At the end, the mobile robots avoid each other and reach their goals successfully.

5 Conclusions and Future Works

We have presented the sensor based vector field histogram method for local obstacle avoidance. The method utilizes raw sensor readings and build map for safe navigation and goal acquisition in environment. SBVFH achieves real-time performance by approximating direction to achieve a goal from online built map. The method needs low communication cost and does not has to explicitly determine the priority of every mobile robots moving in the environment.

The method has been implemented on actual omnidirectional mobile robots. The method provides safe navigation in the environment with several mobile robots moving together.

The future work based on this method is to apply the method to more complex task. We would also like to investigate the method to apply to navigation and/or planning problems. Also the situations, which are people walk-

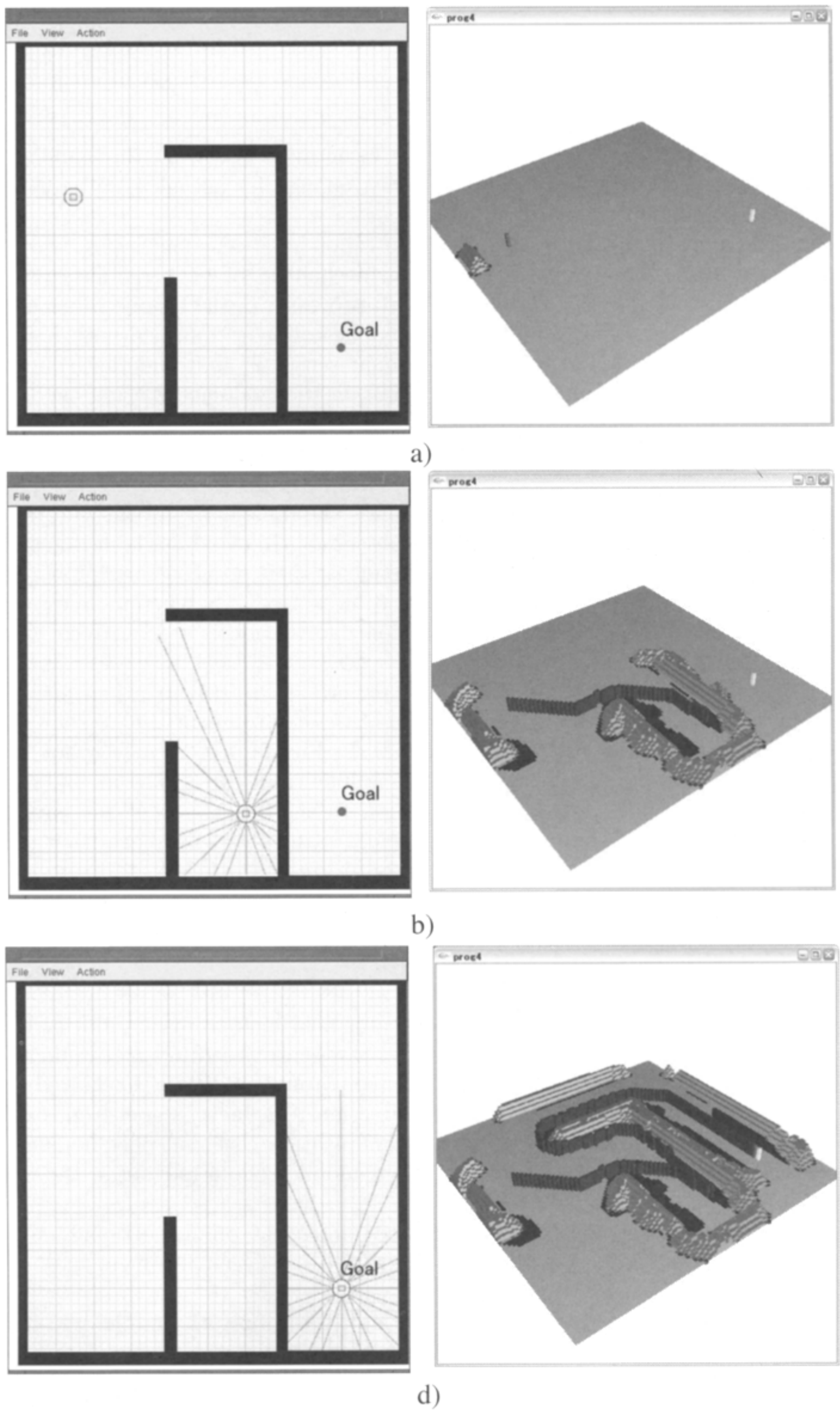

Fig. 5. Navigation and mapping simulation

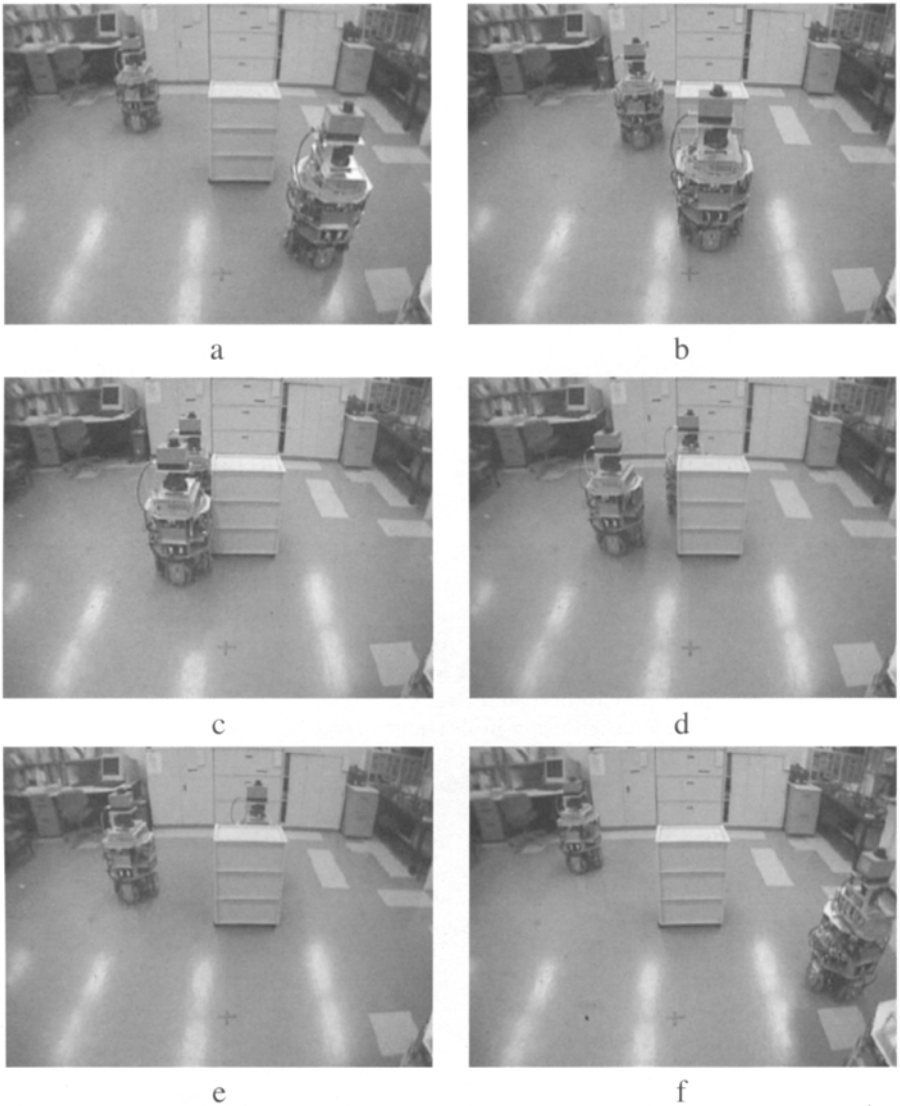

Fig. 6. Experiment with two actual mobile robot

ing in the environment are challenging. The extension and modification for non-holonomic should be made in the near future.

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