A Novel Sonar-Based Obstacle Detection Approach for Sensor-Based Coverage Problem

Erdem Dilmen[1], Ahmet Yazıcı[2], and Osman Parlaktuna[1]

[1]Depatment of Electrical and Electronics Engineering, Eskişehir Osmangazi University, Turkey
erdemdilmen@gmail.com , oparlak@ogu.edu.tr
[2]Department of Computer Engineering, Eskişehir Osmangazi University, Turkey
ayazici@ogu.edu.tr

Abstract

In this paper, a vector-projection-based algorithm is developed to detect obstacles in narrow environments. This algorithm can be used for especially sensor-based coverage problems. The algorithm distinguishes the obstacles from the walls around the robot. Sonar vectors are projected on the edge which the robot moves to detect the obstacles. After detecting the obstacle, the size and location of the obstacle are calculated.

1. Introduction

Autonomous mobile robots must perform their tasks in real time. Goal-oriented tasks may need some sort of path planning and this path must be tracked efficiently while getting information from the environment. Obstacles may be encountered on the path and these obstacles must be detected and avoided. For this purpose; sensors such as laser, camera, infrared range finders, and sonar can be used. Most mobile robots use sonar because of the low price and less computational cost compared to other sensors.

Sonar can also be used for other purposes. Many applications have been realized using sonar. In [1-6], sonar is used for map building. Sonar is also used for localization of mobile robots [7-9]. In [7], sonar data is fused with dead-reckoning to localize the mobile robot. In [10], localization and mapping are achieved by fusing sonar with camera, and in [11] the same goal is achieved by fusing sonar with laser. In [12], a sonar-based obstacle detection method is implemented in autonomous wheel chair. Sonar is also used for geometric structure recognition such as edges, planes and flowers in [13-15]. In [16], obstacle avoidance in narrow corridors was studied. The study was focused on strategic placement of sonar sensors on the mobile robot. In [17], camera and sonar are fused and camera is used for obstacle detection.

Generalized Voronoi Diagram (GVD) techniques are used to model the narrow environments for sensor-based coverage problems [18]. In GVD, the environment is modeled by equidistant edges from the objects in the environment. For many applications; passing on all the edges guarantees complete sensor-based coverage. A path can be constructed such that the robot passes on all the edges [18]. But, due to dynamic nature of environments, some previously unknown obstacles may appear on these edges. Then, the robot cannot follow the planned path. In this case, these obstacles must be detected. But since the environment is narrow, using classical obstacle avoidance methods may lead the robot to detect the walls as obstacles. Therefore, a method should be used which distinguishes the obstacles from the walls of the environment. In this study, a novel obstacle detection approach is proposed to solve this problem using projection of sonar vectors on the GVD-edges.

The rest of the paper is organized as follows. In Section 2, the proposed algorithm is given in details. In Section 3, implementation of the proposed algorithm and comparison with classical obstacle avoidance method are given. Finally, section 4 concludes the paper.

2. The Proposed Algorithm

In the proposed algorithm, the obstacle is detected by sonar. The position and the size of the obstacle are determined using laser.

2.1. Obstacle Detection

The mobile robot is supposed to follow the planned path consisting of a number of GVD-edges. Each one of these edges are called as *desired edge (DE)*. But, the robot may not be exactly on *DE* (Fig. 1). The edge on which the robot is actually moving is called *actual edge (AE)*. The *AE* starts at the center of the robot and ends at the end point of the *DE*. The *edge distance (d)* is the distance of the center of the robot to *DE*. The angle between the robot's local *X* axis and the *AE* is $(a+b)$ degrees.

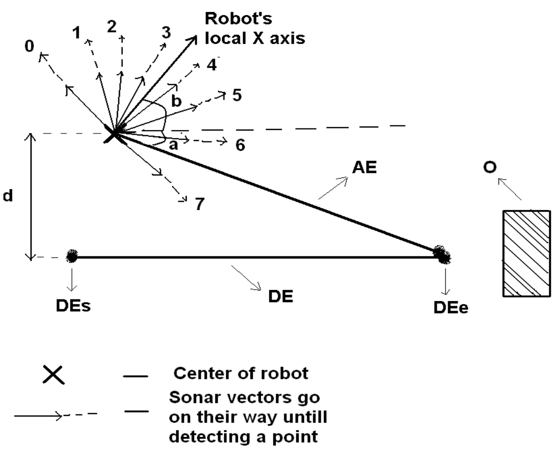

Fig. 1. Projection of sonar vectors workspace

The location and orientation of the robot with respect to a global coordinate system are assumed to be known precisely. Each sonar measures the distance of an obstacle relative to the robot, and this distance should be transformed into the global coordinate system. By using the transformed sonar readings, *sonar vectors* are calculated in the global coordinate system. These *sonar vectors* are used in projection operations. S*onar vectors* start at the center of the robot and end at the detected point. The placement and orientation of sonar sensors on P3-DX mobile robots are given in Fig. 2. Angle of each sonar relative to the local X axis of the robot is 90^0, 50^0, 30^0, 10^0, -10^0, -30^0, -50^0, -90^0 for indexes 0 to 7, respectively.

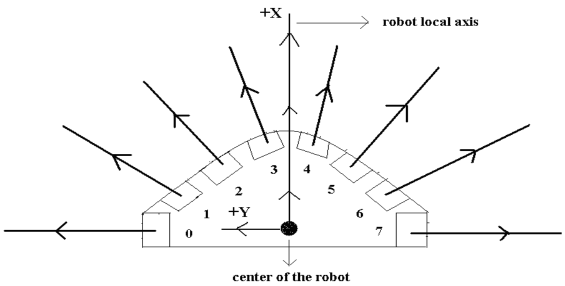

Fig. 2. Sonar array on the front side of the mobile robot P3-DX

The steps of the algorithm are as follows.

Step 1: Get the distance values $(r_i,\ i = 0,...,7)$ obtained by the sonars.

Step 2: The closer objects (wall or obstacle) must have the greater effects in the obstacle detection process. Therefore, distance values are normalized using equation (1).

$$N1_i = \begin{cases} m_1 \times (r_i - \text{range}_{\max}) & r_i \le \text{range}_{\max} \\ 0 & otherwise \end{cases} \qquad (1)$$
$$where \quad m_1 = -(10 \div \text{range}_{\max})$$

In this equation, $\text{range}_{\max}$ denotes the maximum distance that can be measured by the sonar. Here, $N1_i$ is the output of normalization for $i = 0,...,7$.

Step 3: Perform a second normalization for d. The second normalization function is given in equation (2).

$$N2_i = \begin{cases} 0.4 + m_2 \times (d - d_{\max}) & d \le d_{\max} \\ 0 & otherwise \end{cases} \qquad (2)$$
$$where \quad m_2 = -(0.6 \div d_{\max})$$

With this normalization, the effects of sonar readings are reduced if the robot is getting further from the *DE*. $N2_i$ is the output of the normalization function for $i = 0,...,7$.

Step 4: The final normalized values, (Nf_i), are the magnitudes of the *sonar vectors* after two normalization processes.

$$Nf_i = N1_i \times N2_i \times r_i,\ i = 0,...,7 \qquad (3)$$

Step 5: The magnitude of projection (P_i) of all 8 *sonar vectors* on the *actual edge* are calculated as in equation (4)

$$P_i = |Nf_i| \times \cos(\alpha_i) \qquad i = 0,...,7 \qquad (4)$$

where α_i is the angle between the *sonar vector*$_i$ and the *AE*. If the magnitude of any of the projection is greater than *Obstacle detection threshold value*, it is concluded that an obstacle is detected.

3. Experimental Results for Obstacle Detection

The proposed algorithm was tested in in ESOGU AI and Robotics Laboratory. Map of the test environment is shown in Fig. 3. This environment is transferred to MobilSim simulation environment for simulation purposes. The width of the corridors used in the experiments is about 1200 mm and the *safe-path width,* which is obtained by considering the width of the robot and a safe margin, is 600 mm. Although sonar can detect 5 meters away, due to the dimensions of the working environment, the $\text{range}_{\max}$ is selected as 600 mm. The value of $d_{\max}$ is chosen as 300mm. 3 is used as the value of *Obstacle detection threshold value.* A rectangular obstacle with dimensions of (450x250) mm is placed in the environment Coordinates of corners of the obstacle are: (1800, 2400), (1800, 2850), (2050, 2850), and (2050, 2400), and d*esired edge* of the robot starts at (1000, 3000) and finishes at (3000, 3000).The robot is located at the positions (1300, 3000), (1500, 3000), and (1900, 3250) as shown in Figs. 4-6, respectively. The direction and magnitude of each sonar vectors are also given in these figures. Magnitudes of the projected *sonar vectors* as a result of obstacle detection algorithm are shown in Table 1.

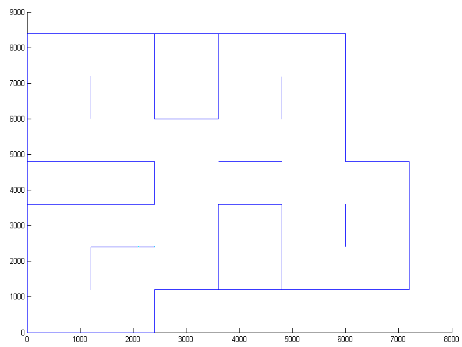

Fig. 3. The map used in experiments

Table 1. Magnitudes of projection results

	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7
Fig 4	0.1	0	0	0	4.0	2.6	0	0.1
Fig. 5	0	0	0	0	7.1	5.9	3.3	0.2
Fig. 6	0	0	0	0	0	0	0	0

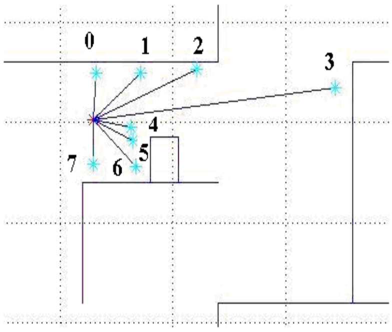

Fig. 4. The first position

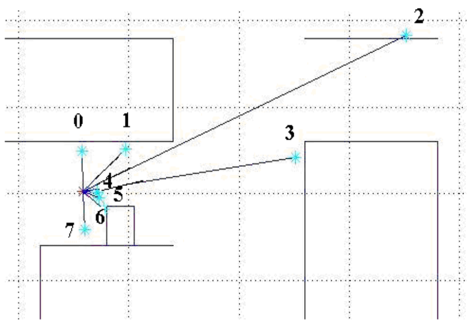

Fig. 5. The second position

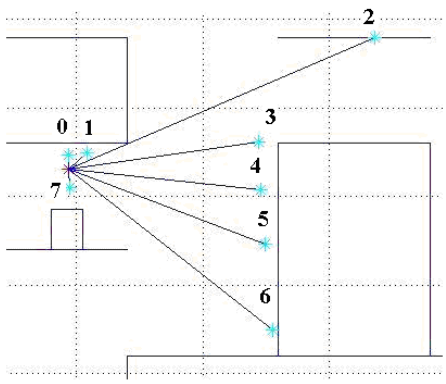

Fig. 6. The third position

As shown in the Figs 4-6, the mobile robot never detects any wall as an obstacle. As seen in Table 1, only the *sonar vectors* which detect a point on the obstacle within $range_{max}$ may return a value greater than *obstacle threshold value* after the normalization and projection processes. In Fig. 5, three sonar vectors returned a value greater than *obstacle threshold value*. The value returned by P_4 is the greatest and the point detected by the 4^{th} sonar will be used as *biggest valued point* in navigation. Also in Fig. 6, only 7^{th} sonar detects a point on the obstacle but the angle between it an *AE* is -90^0. Therefore, the projection of the corresponding *sonar vector* on *AE* returns zero which means that this obstacle does not block the robot path.

3.1. Navigation

When an obstacle is detected, the robot stops. Then, SICK LMS 200 laser range finder is used to determine the position and size of the obstacle. In navigation process, the *biggest valued point* which was already calculated in the obstacle detection process is used to evaluate the laser values..

Using these values; the algorithm checks for the dimension of the free-way that the mobile robot can pass safely. Fig. 7 shows a possible path to avoid the obstacle.

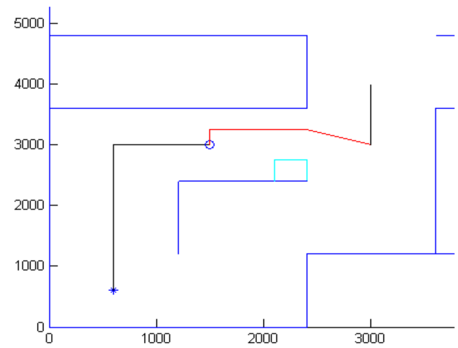

Fig. 7. A possible sub-route

3.2. Implementation and Comparison of the Algorithm

The both obstacle detection and navigation algorithm are coded in C++ and tested in MobilSim simulation environment. The overall algorithm is compared with the classical obstacle avoidance method. Three obstacles are placed in the environment. As seen in Fig. 8, classic obstacle avoidance method was unsuccessful and the robot could not follow the planned path. But as seen in Fig. 9, the proposed algorithm leads the mobile robot to follow the planned path successfully.

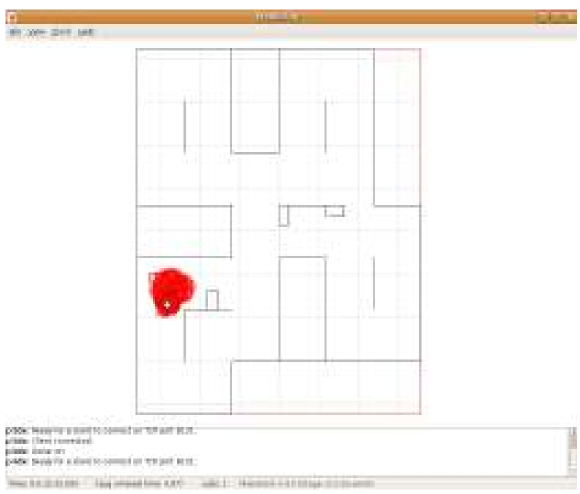

Fig. 8. Result of classical obstacle avoidance method

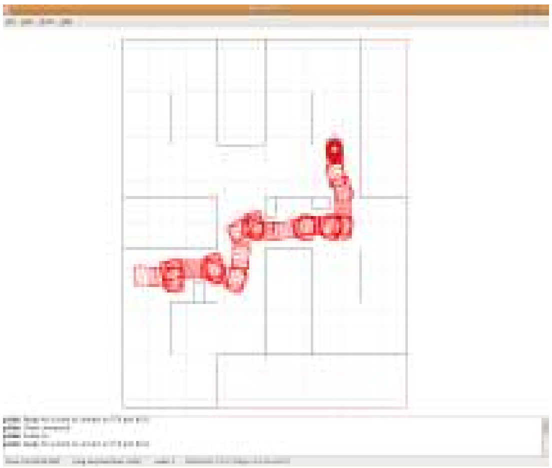

Fig. 9. Result of the proposed algorithm

4. Conclusion

In sensor-based coverage problems, it is critical to distinguish the obstacles on the path from other obstacles such as walls. In this study, an obstacle detection method is proposed. With this algorithm; obstacles are distinguished from the walls, because the robot is only interested with the obstacles which are on its way, actually on the edge on which it is moving on.

Since simple projection operators are used to detect the obstacle, the proposed algorithm is very efficient for real time obstacle detection while executing all navigation behaviors. After detecting the obstacle, the mobile robot stops and uses laser to detect the size and position of the obstacle more precisely. Then, if there is a safe path, the robot continues its motion.

Acknowledgment

This work is supported by the Scientific and Technical Research Council of Turkey (TUBITAK), Contract No 107E064, project title: “Mobile Robot Route Planning for Complete Coverage of Dynamic Indoor Environments”.

5. References

[1] K. S. Chong, L. Kleeman, "Mobile-Robot Map Building from an Advanced Sonar Array and Accurate Odometry", *IJRR*, vol. *18,* no. *1,* pp. *20-36,* Jan., 1999.

[2] B. K. Min, D. W. Cho, S. J. Lee, Y. P. Park, "Sonar Mapping of a Mobile Robot Considering Position Uncertainitiy", *Robotics & Computer Integrated Manufacturing*, vol. *13,* no. *1,* pp. *41-49,* Mar., 1997.

[3] H. P. Moravec, A. Elfes, "High resolution maps from wide angle sonar", *IEEE International Conference on Robotics and Automation*, 1985, pp. *116-121*.

[4] J. Borenstein, Y. Koren, "Histogramic In-Motion Mapping for Mobile Robot Obstacle Avoidance", *IJRA*, vol. *7,* no. *4,* pp. *535-539,* Aug., 1991.

[5] M. A. K. Jaradat, R. Langari, "Line Map Construction using a Mobile Robot with a Sonar Sensor", *IEEE International Conference on Advanced Intelligent Mechatronics*, Monterey, California, 2005, pp. *1251-1256*.

[6] S. Kodagoda, E. A. S. M. Hemachandra, P. G. Jayasekara, R. L. Peiris, A. C. De Silva, R. Munasinghe, "Obstacle Detection and Map Building with a Rotating Ultrasonic Range Sensor using Bayesian Combination", *IEEE International Conference on Information and Autuomation*, Shandong, 2006, pp. *98-103*.

[7] C. C. Tsai, "A Localization System of a Mobile Robot by Fusing Dead-Reckoning and Ultrasonic Measurements", *IEEE Transactions on Instrumentation and Measuerement*, vol. 4*7,* no. *5,* pp. *1399-1404,* Oct., 1998.

[8] I. Ashokaraj, A. Tsourdos, B. White, P. Silson, "Robot Localization using Interval Analysis", *Sensors, 2003, Proceedings of IEEE*, vol. *1,* pp. *30-35,* Oct., 2003.

[9] H. H. Lin, C. C. Tsai, J. C. Hsu, C. F. Chang, "Ultrasonic Self-Localization and Pose Tracking of an Autonomous Mobile Robot Via Fuzzy Adaptive Extended Information Filtering", *IEEE International Conference on Robotics and Automation*, Talpei, Taiwan, 2003, pp. *1283-1290*.

[10] X. C. Lai, C. Y. Kong, S. S. Ge, A. A. Mamun, "Online Map Building for Autonomous Mobile Robots by Fusing Laser and Sonar Data", *IEEE International Conference on Mechatronics and Automation*, Niagara Falls, Canada, 2005, pp. *993-998*.

[11] J. Choi, S. Ahn, M. Choi, W. K. Chung, "Metric SLAM in Home Environment with Visual Objects and Sonar Features", *IEEE International Conference on Intelligent Robots and Systems*, Beijing, China, 2006, pp. *4048-4053*.

[12] G. D. Castillo, S. Skaar, A. Cardenas, L. Fehr, "A Sonar Approach to Obstacle Detection for a Vision-Based Autonomous Wheelchair", *Robotics and Autonomuos Systems*, vol. 54*,* no. *12,* pp. *967-981,* Dec., 2006.

[13] J. A. Jimenez, J. Urena, M. Mazo, A. Hernandez, E. Santizo, "Three-Dimensional Discrimination Between Planes, Corners and Edges Using Ultrasonic Sensors.", *IEEE Conference on Emerging Technologies and Factory Autuomation*, 2003, pp. *692-699*.

[14] N. Harper, P. M’Kerrow, "Recognizing Plants with Ultrasonic Sensing for Mobile Robot Navigation", *Third European Workshop on Advanced Mobile Robots*, Zurich, Switzerland*,* 1999, pp. *105-112*.

[15] D. Diep, A. Johannep, P. Bonnefoy, F. Harroy, P. Loiseau, "Classification of Sonar Data for a Mobile Robot using Neural Networks", *IEEE International Joint Symposia on Intelligence and Systems*, pp. *257-260,* May, 1998.

[16] V. Q. Nguyen, S. B. Oh, H. C. Ro, C. J. Cho, S. H. Han, "A Study on Obstacle Avoidance of Mobile Robot.", *International Conference on Control, Automation and Systems*, Seoul, Korea, 2008, pp. *2384-2389*.

[17] S. Nara, S. Takahashi, H. Ishihara, "Trajectory Navigation for Mobile Robot.", *IEEE International Conference on Advanced Intelligent Mechatronics*, Zurich, 2007, pp. *1-6*.

[18] O. Parlaktuna, A. Sipahioglu, G. Kirlik, A. Yazici, “Multi-robot sensor-based coverage path planning using capacitated arc routing approach”, *24th IEEE International Symposium on Intelligent Control*, Russia, July 8-10, pp.1146-1151, 2009.