Obstacle Avoidance Behavior of Autonomous Mobile Robot using Fiber Grating Vision Sensor

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Abstract

In this paper, we mention realization of obstacle avoidance behavior of autonomous mobile robot in an unstructured indoor environment. To reach a goal by avoiding obstacles, it is necessary not only to avoid collision but also to return to the original planned path. We propose an algorithm which can realize obstacle avoidance behavior considering blind space which arises from the limitation of field of view of the sensor system. We used a Fiber Grating 3D vision sensor in order to avoid obstacles considering 3D shape of objects. To realize real-time obstacle detection, we developed a fast image processing method. We show the effectiveness of our method through an experimental result using a real mobile robot.

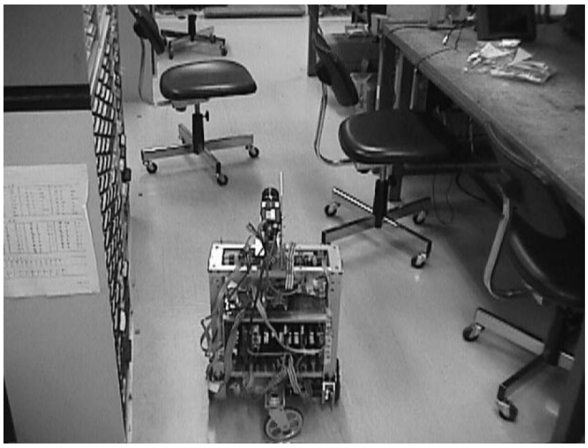

Figure 1: Target unstructured environment.

1 Introduction

The purpose of this study is to realize obstacle avoidance behavior of an autonomous mobile robot according to the 3D shape of objects and the robot itself in an unstructured real environment (see Fig.1). For this purpose, a sensor which can recognize the environment three-dimensionally is needed. A compact and light-weight one is better because it will be mounted on a mobile robot, so we adopt a 3D range sensor which uses Fiber Grating[1] in this research.

Up to now, we have made the robot able to find the passage space using Fiber Grating vision sensor[2]. In that method, a laser spot array is projected on the floor and obstacles are detected by checking the projected position of laser spots[3]. However, it couldn't apply to height limited passages (Fig.2). To overcome this problem, we changed the sensor configuration so that the laser spots are projected to the front direction of the robot.

In order to realize obstacle avoidance behavior, it is necessary not only to detect obstacle and to find a passage, but also to return to the original path. However it is usually difficult to go back to the original path properly after completion of avoidance, since the robot cannot judge well whether avoidance was completed or not. It is because the field of view of the sensor is limited to a certain range and because the robot cannot see the obstacle which is being avoided. Here, we tried to solve this problem by giving the sensor a function of rotation(pan).

In this paper, we describe first the outline of the 3D environment recognition using Fiber Grating vision sensor. Next, the method for finding passage space for the robot based on the sensor information is explained. Then we propose a method for obstacle avoidance. Finally we show the feasibility of this method through some experimental results.

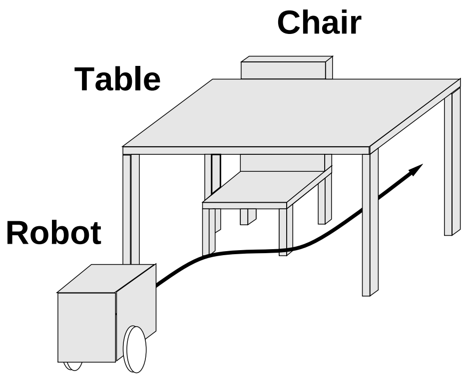

Figure 2: Obstacle avoidance considering 3D shape of objects.

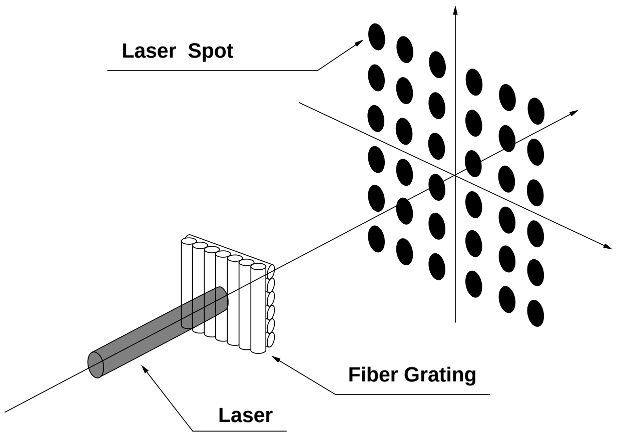

Figure 3: 2-dimensional spot array generated by Fiber Grating.

2 Fiber Grating Vision Sensor

2.1 Fiber Grating[1]

Fiber Grating (FG) is a diffraction grating which is constructed from two overlaid fiber sheets crossing at right angle. Each sheet consists of several hundred optical fibers lined densely. When the FG is irradiated by laser light, each optical fiber behaves as a cylindrical lens and laser light is condensed and diverges spherically. Each spherical wave interfere one another and tetragonal array of spot light is generated ahead of the FG as shown in Fig.3.

Figure 4: Photo of FG vision sensor system.

2.2 Devices of the sensor system

Fiber Grating vision sensor (FG vision sensor)[2] is an active vision sensor using a FG, a laser diode, and a CCD camera(Fig.4). The spot array is generated by a FG, reflected light is detected by CCD camera, and a 3D range image is obtained by triangulation. A filter is set on the camera to select only the reflected light of the laser and remove the other light. The whole sensor system is mounted on the top of the robot at a height of about 60cm from the floor.

3 Real-time Obstacle Detection in 3D Environment

3D position of each laser spot projected on the object can be obtained using FG sensor. However it still takes long time for real-time obstacle avoidance. Therefore we propose a new technique to detect obstacles existing in front of the robot.

3.1 Concept of *Search Space*

Let's consider an robot is moving on a planned path. Next moment, the robot will path through the space having a certain volume on the path. The robot has to know whether anything exists or not just in this space in order to avoid collision. More concretely, it can be a box in 3D space which is 1∼2m ahead of the robot and has enough height and width for the robot to pass as shown in Fig.5. Here, we named this space *Search Space*. Because the existence of any obstacles in the *Search Space* can be checked very quickly by the method explained in the next subsection, the robot able to realize real-time obstacle avoidance.

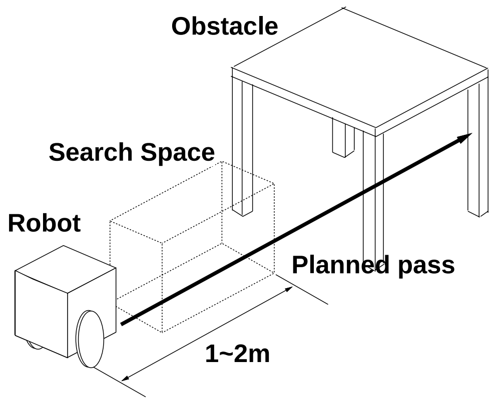

Figure 5: Concept of *Search Space*.

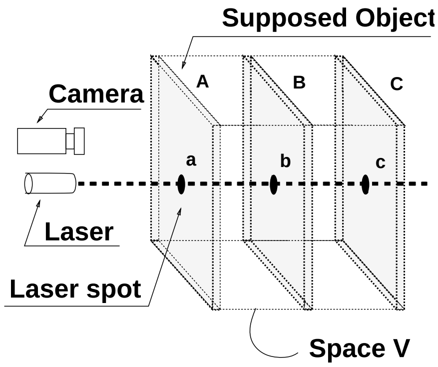

Figure 6: Imaging of a laser spot by a camera according to the distance from the sensor(laser and camera).

3.2 Movement of the spot

Let's consider a certain spot in the array. Fig.6 shows a scene where an object is put in front of the sensor system and is observed by a camera. a,b,c are reflecting points of the laser when the object is put at position A,B,C, respectively. By piling up three camera images, an image like Fig.7 is obtained. As the object moves away from the sensor (like A→B→C), the spot in a image moves up (like a'→b'→c'). If we consider each spot, we can obtain the moving area of the spots like Fig.8. We call this area in the image "*Mask Area*".

3.3 Fast obstacle detection

Spots will appear in the *Mask Area* when some objects are present in the space 'V' in Fig.7. Therefore, it is possible to know whether there is something or

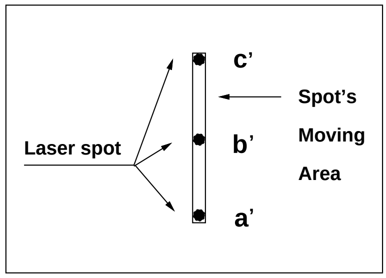

Figure 7: Movement of a spot in the camera image.

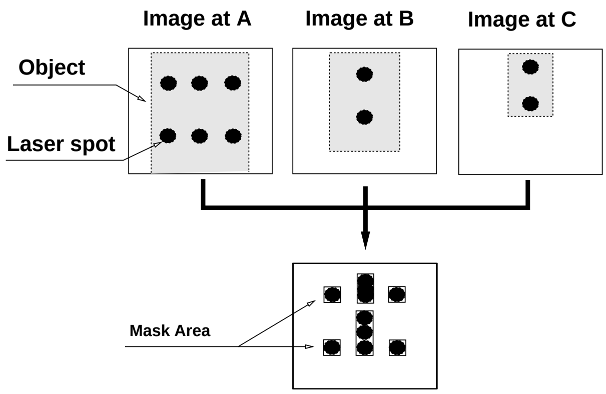

Figure 8: *Mask Area* for the space 'V' in Fig.6.

not in the space 'V' by checking whether spots appear on somewhere of *Mask Area* or not. The space 'V' is able to have an arbitrary shape by making the corresponding *Mask Area*.

As a calibration process, we build a data of *Mask Area* by moving a plane object in the *Search Space* in advance (see Fig.9). On the autonomous navigation stage, the robot checks whether the spots appear on the *Mask Area* or not. It is done so quickly that the robot can know the existence of an obstacle in real-time.

4 Obstacle Avoidance Behavior

4.1 Changing a way to avoid collision

Algorithm of collision avoidance using Search Space is as follows. The robot runs on the planned path when nothing is found in the *Search Space*. If any object is found, the robot does collision avoidance by searching new passage and entering there. Here, we

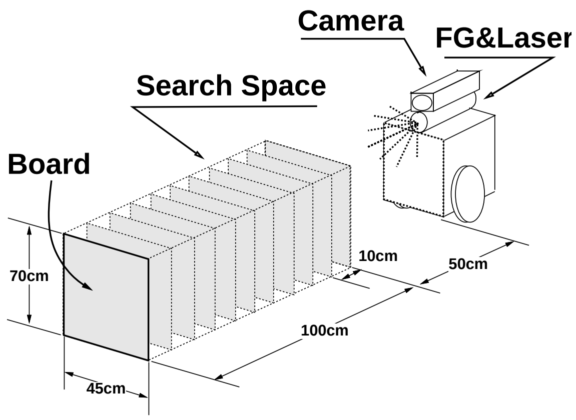

Figure 9: Calibration process for making *Mask Area*.

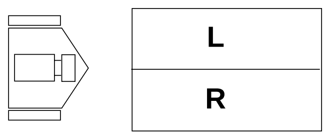

Figure 10: Division of *Search Space* for collision avoidance. If some object exist in R(L), the robot turns L(R). If some object exists in both sides(R and L), the robot stops and searches a new good passage.

divide the *Search Space* into right and left parts as shown in Fig.10. When some obstacle is found in the right (or left) side of the *Search Space* only, the robot can avoid it without stop by changing its way into left (or right). And if there are some objects in both sides, the robot stops in order to search a new good passage by turning the sensor direction to left and right.

4.2 Return to the original path

Using this algorithm, the robot is just able to run avoiding obstacles one after another. However, the robot is expected to return to the planned original path after the completion of avoidance in order to reach the goal. To realize this "Obstacle Avoidance Behavior" including also the return to the original path, the robot must observe the obstacle being avoided and time properly the timing to start returning to the original path. For this purpose, we have given the sensor system a function of the rotation(pan) so that the robot can check not only front but also the direction it wants to go next (Fig.11).

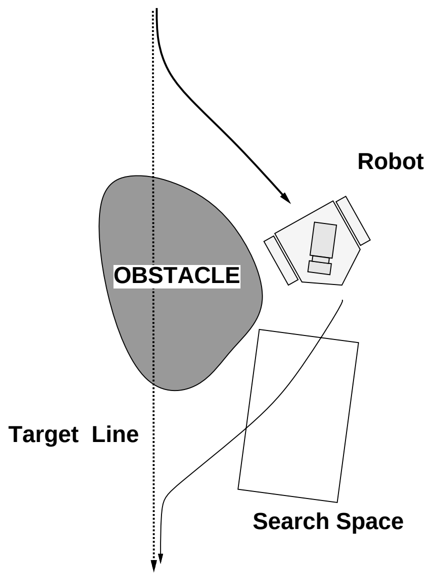

Figure 11: Obstacle avoidance behavior with panning.

4.3 Consideration of blind space

Because of its characteristics, the FG vision sensor cannot see very close region[2]. So we have to aware that the direction judged to be free by the sensor system using the pan is not always a real passage.

As shown in Fig.12, the robot goes straight and has just panned θ degrees. In this figure, area 'A' is real free space based on the check which has been done up to now. Area 'B' is the space which is really free when the robot pans and finds nothing in the *Search Space*. Area 'C' is inner space of the *Search Space* and unknown whether it is really free or not even if the robot finds nothing there. Area 'D' is the unknown space which is out of the *Search Space* because it is too close to the robot. It's because the spot array of the FG cannot reach area 'C' if something exists in the area 'D' that we cannot affirm that area 'C' is free. So we must take care of the fact that unknown spaces like area 'C' and 'D' could exist. If the robot turns into ignoring these areas, there is some risk of engulfing the obstacle overlooked. So the robot must go forward a certain distance more when it pans and finds nothing in the search space, and after that, it can turn into area 'B' in order to turn without engulfment.

4.4 Algorithm of obstacle avoidance

A state transition graph of the algorithm is shown in Fig.13. This is an algorithm to make robot run

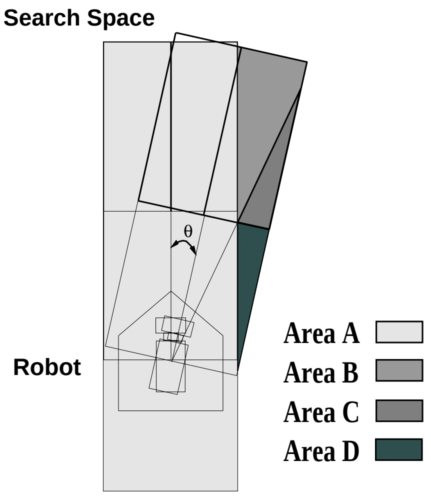

Figure 12: Occurrence of blind space in the sensing strategy with panning.

along a target line given by the user, and avoid obstacle by falling off the path if some object exists on the path, and return to the original path after completion of the avoidance autonomously. The robot checks front on the planned path basically. When the robot runs away from planned path and wants to return to the original path, it makes sure the safety of the front direction first, and pans and searches a return path. If the return path is found, according to the former subsection, the robot establishes a certain distance ahead as a *Sub Goal(SG)*, and after the arrival at the *SG*, it starts the return behavior. If the robot finds some obstacle in front of itself, it avoids the obstacle by turning immediately without considering engulfment as an emergency avoidance.

5 Experiment of Obstacle Avoidance

5.1 Experimental system

A photo of the sensor system is shown in Fig.14. It consists of *FG vision sensor* and has a function of pan. The system is mounted on the autonomous mobile robot "*Yamabico*"[4].

5.2 Contents of Experiment

Experiment was done in the corridor in front of our laboratory. Fig.15 shows the environment. The robot was ordered to run 18m along the straight line which was center of corridor. On this target line, cardboard boxes and resin pipes were set as obstacles. In this experiment, we especially paid attention to the return behavior after completion of avoidance.

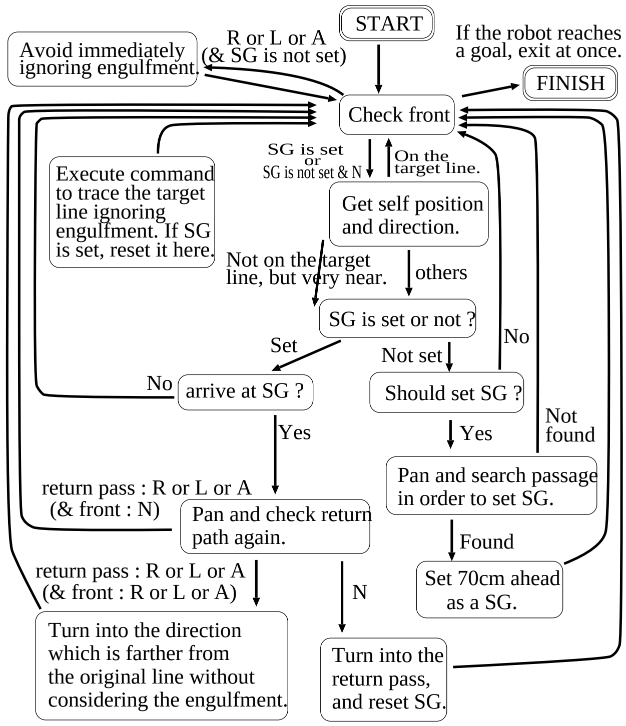

Figure 13: State transition graph of the obstacle avoidance algorithm. R, L, A, N mean Right, Left, All(both R and L) and None, respectively where obstacle is found in the *Search Space*

5.3 Results and Consideration

Odometory data of robot during the experiment is plotted in Fig.16. Target line given to the robot is a straight line from (0,0) to (18000,0), and a solid curve line is the locus that the robot has passed. Now, we can make sure that the robot once fell off the target line and avoid the obstacle when an obstacle exist on the target line, and it returned to the target line considering engulfment after the completion of avoidance autonomously. But on the other hand, because of the algorithm that makes the robot starts returning to the original path after it has run over certain distance from where it found the return path, there are some possibilities that the robot returns making a too big detour. Besides the locus of the robot overlaps with a resin pipe in the figure. This is the proof that the robot(height:60cm) could pass under the pipe(height:73cm) with making sure of safety.

6 Conclusion

In this paper, we have described a method for obstacle avoidance of an autonomous mobile robot. We used Fiber Grating 3D vision sensor in order to consider the 3D shape of objects. In order to reach the goal, it is necessary not only to avoid collision but also to return to the original planned path. We have proposed an algorithm to realize it using a sensor system having a panning function. We have also developed a fast image processing method to realize real-time obstacle detection. As a result of experiment, we could see that the robot succeeded to realize obstacle avoidance including the return to the original path. In future work, generation of more smart detour path in the returning behavior will be developed and moving obstacles will be dealt with as well.

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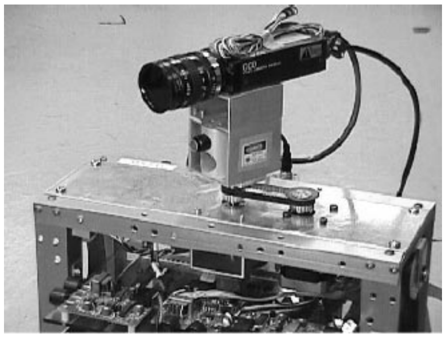

Figure 14: Sensor system mounted on the top of the mobile robot. It has a function of rotation(pan).

Figure 15: Experimental environment. Several cardboard boxes and resin pipes are placed in a corridor as obstacles.

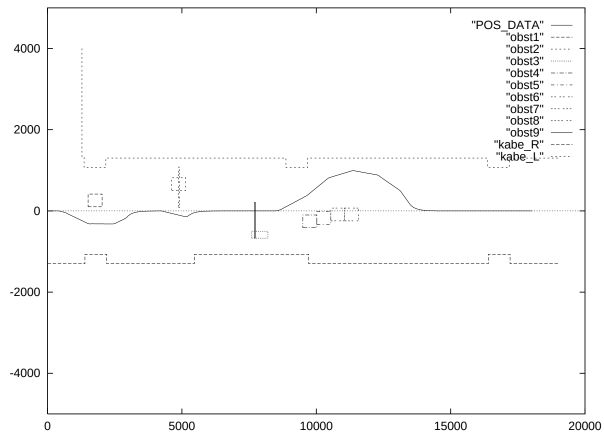

Figure 16: Odometery data of the robot in the experiment.