Real-Time Obstacle Avoidance by an Autonomous Mobile Robot using an Active Vision Sensor and a Vertically Emitted Laser Slit

Seydou SOUMARE*, Akihisa OHYA** and Shin'ichi YUTA*
*Intelligent Robot Laboratory, University of Tsukuba
**PRESTO, JST / University of Tsukuba
1-1-1 Tennodai, Tsukuba, 305-8573 JAPAN
{soumare,ohya,yuta}@roboken.esys.tsukuba.ac.jp

Abstract: *This article presents a real-time vision-based obstacle detection and avoidance method in an indoor environment for an autonomous mobile robot. In this study, we propose a scenario in which 3-Dimensional obstacles mainly building our real world environment, are detected by scanning a vertically emitted laser slit paired with an active stereo vision system. We present a simple and effective obstacle avoidance algorithm and experimental results to illustrate the advantages of our approach.*

Keywords: *Mobile robot, Obstacle avoidance, Laser range sensor, Active stereo vision.*

1 Introduction

For an autonomous mobile robot performing a navigation-based task in a vague environment, to detect and to avoid encountered obstacles is an important issue and a key function for the robot body safety as well as for the task continuity. Obstacle detection and avoidance in a real world environment - that appears so easy to humans - is a rather difficult task for autonomous mobile robots and is still a well-researched topic in robotics.

In many previous works, a wide range of sensors and various methods for detecting and avoiding obstacles for mobile robot purpose have been proposed. Good references related to the developed sensor systems and proposed detection and avoidance algorithms can be found in [1-11].

Based on these developed sensor systems, various approaches related to this work can be grouped into two categories. The first one tends to use ultrasonic sensors for their simple implementation and fast obstacle detection, but they show great accuracy and reliability limits when it comes to detect obstacles having a 3-Dimensionally complicated shape[1][2][3][4]. On the other hand, we have the vision-based sensor systems, which can be divided into two subgroups of sensor systems: stereo vision and laser range sensors. The former one applies with good reliability to the detection of 3-Dimensional objects but reveals to be deficient in term of speed and towards weakly textured obstacles[5][6][7][8]. The latter one, when applied as an horizontally emitted laser range sensor is efficient only towards 2-Dimensional obstacles[9][10]. We have also, 2-Dimensional laser range finder sensor which can efficiently detect 3-Dimensional obstacles but is poorly characterized in real-time detection[11]. From this background, the

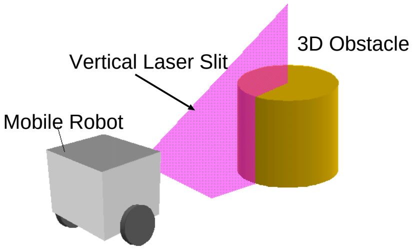
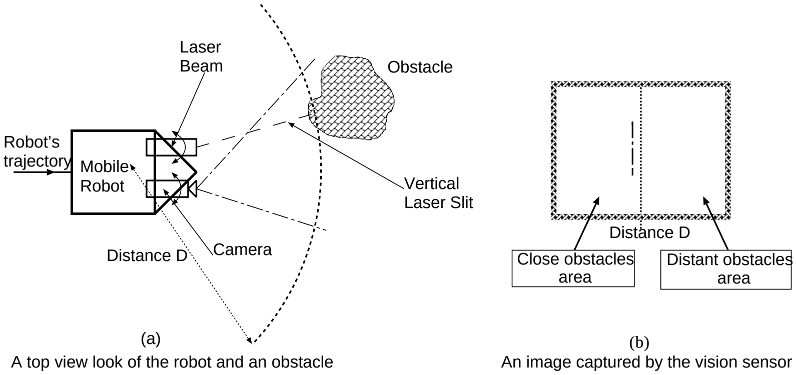


Figure 1: The vertical emission of the laser slit.



(a)
A top view look of the robot and an obstacle

(b)
An image captured by the vision sensor

Figure 2: Obstacle detection principles.

main contribution of this work is the realization of an accurate, reliable and real-time obstacle detection and avoidance conducted in an indoor environment by an autonomous mobile robot using an active vision sensor coupled with a vertically emitted laser slit.

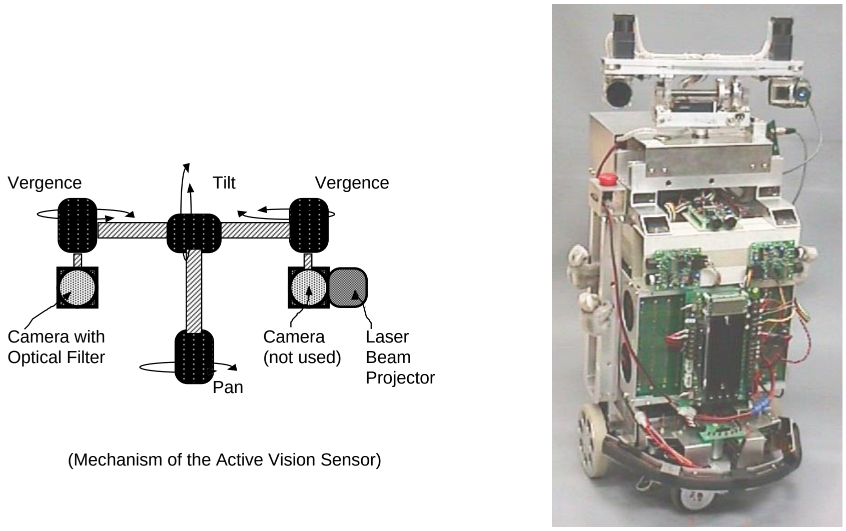
In this paper, we introduce first our obstacle detection strategy, using an active stereo vision system paired with a vertical laser slit and its implementation. Next, we outline the control of the viewing field of the robot during its navigation. Last, we present briefly the obstacle avoidance algorithm applied in this work and yet show the experimental results of an obstacle avoidance action that took place in a corridor.

2 Obstacle detection

2.1 Principles

In this study, we use a laser range sensor to detect obstacles. A laser range sensor consists of coupling a vision sensor with an -usually- horizontally emitted laser slit. It enables an intelligent robot to get the distance to any obstacle present in its 2-Dimensional vicinity, thanks to a simple and speedy image processing[12]. However, emitting horizontally the laser slit does not procure the height information of obstacles such as tables, chairs and many others present in an indoor environment. In this work, in order to obtain the height information of any object obstructing the robot path, regardless of its shape, we emit our laser slit vertically as illustrated in figure 1.

As shown in figure 2(a), the laser range sensor components are set with the mobile robot. From the laser beam projector is emitted a vertical laser slit which is reflected when it encounters an obstacle, and is captured by the vision sensor(figure 2(b)). On an



(Mechanism of the Active Vision Sensor)

Figure 3: Autonomous mobile robot equipped with active stereo vision and vertically emitted laser projector.

image captured by the camera, an obstacle appears as a vertical segment. Its horizontal coordinates taken from the image left border correspond to the obstacle position viewed from the robot center. For each captured image, computing an obstacle position from the robot center will not fulfill our seek for a real-time obstacle detection, since it is a time-consuming image processing. Instead, we fix a threshold distance under which obstacles on the mobile robot's path would be detected quickly and accurately. For instance, if we suppose that the image's vertical center line represents a given threshold distance D from the robot center, then a vertical segment representing any obstacle that appears on the left-side of our vertical line threshold, we can say that such an obstacle should exist in the immediate vicinity of the robot, within a distance D from its center. On the other hand, if the segment happens to be on the right-side of the threshold line, we deduce that the obstacle is located beyond a distance D from the robot position. Thus, by checking constantly the image's left-side region, we enable our sensor to detect efficiently and quickly any obstacle standing in its front neighborhood.

However, since the vision sensor and the vertical laser slit, making our laser range sensor, are sensing in only one direction, which is insufficient to know the presence of obstacles standing on the robot's path. The above explained detection method is basically not relevant enough and needs to be ameliorated. The main improvement brought to this detection method is to change the meeting point of the laser beam projector and the vision sensor, in other words to scan our sensor throughout all the mobile robot front environment thanks to actuators (active vision).

Therefore, scanning horizontally a vertical laser slit throughout the robot front environment and capturing and checking constantly the image's left region would enable a robot equipped with such sensor to detect quickly and efficiently any obstacle present in its front neighborhood.

2.2 Sensor system hardware

In this research, the authors used an active stereo vision system[13], set on the top of our YAMABICO robot[14], the intelligent mobile robot jointly used in this study (figure 3). The mechanism of this sensor system is mainly made up of four degrees

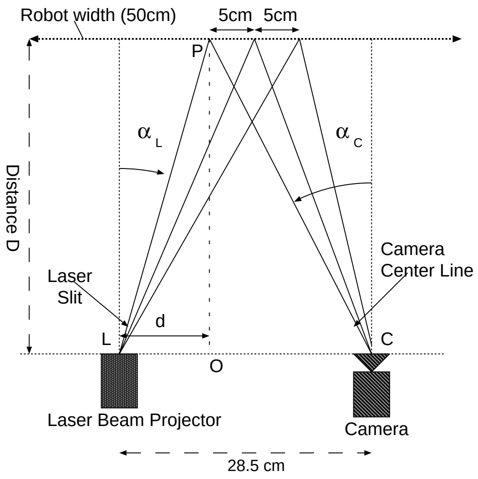


Figure 4: Obstacle detection range related to the vergences.

of freedom: pan, tilt and two independent vergences. Under each vergence, a camera is fixed as illustrated in figure 3. We only used the robot's right hand side camera through an optical filter which cuts visible lights and paired it with an infrared laser beam projector set with the robot's left vergence. Below, we outline that activating both vergences enables our laser range sensor to scan effectively and quickly the mobile robot vicinity.

2.3 Strategy and implementation

The above introduced method has been implemented on our YAMABICO robot. Then, once our laser range sensor was defined and set with our mobile robot, we had to define quantitatively its range of detection consisting of a 3-Dimensional area in which obstacles must be detected reliably and speedily. We defined such an area with features, such as the detection distance of an obstacle, the robot's height and width.

Firstly, the detection distance of an obstacle, viewed from the robot center, relies deeply on the intersection of the camera center line and the vertical laser slit. Recursively, this will depend on the rotational angles of both vergences, as our laser range sensor's components are activated by these actuators. In figure 4, α_L and α_C represent respectively the rotational angle of each vergence. The distance D of an obstacle location from the robot is related to the rotational angles of each vergence, as follows.

$$D = LC/\left(\tan\alpha_L + \tan\alpha_C\right)(1) \quad \text{for any } \alpha_L, \alpha_C \text{ (with LC=28.5 cm)}$$

Moreover, another critical issue here is to precise how wide the robot should search for possible obstacles on its path. We recall that the need of scanning our sensor throughout the robot's path, is due to the vertical emission of the laser slit in one direction which reveals to be ineffective and not enough to secure the robot's body safety against any sided obstacle near the path. Therefore, the mobile robot must scan constantly its own width on the path in order to continue safely its navigation-based task. In this implementation, our YAMABICO robot has a 50 cm width that we slice into ten segments of 5 cm each. We then, orient periodically our sensor on each segment thanks to the vergences. In figure 4, we first set the laser beam projector(left vergence) on one segment and doing so will direct the vision sensor(right vergence) on the same vergence according to these following expressions.

$$\alpha_L = \tan^{-1}(d/D) \; (2) \quad \text{and} \quad \alpha_C = \tan^{-1}((LC - d)/D) \; (3)$$

d : distance to any segment from the laser beam projector.

In the above expressions, both α_L and α_C angles are related to D, the distance of an obstacle from the robot. The capital issue here is to precise how distant -D- our sensor should detect obstacles standing on the robot's path which generally consists of a mix of lines and curves. In our implementation, we set the distance D dynamically in relation with the path complexity and the robot's velocity relative to the path. For instance, if we suppose that the mobile robot follows a linear path, our sensor is then able to search far ahead any obstacle present on the route. However, when the path is circular, the detection distance D should be small enough to enable our sensor to detect any obstacle standing on the forthcoming circular path. Path complexity in this study is basically acknowledged by setting high velocity for linear paths and relatively slow velocity for circular paths. This yields us to have the obstacle detection distance D proportional to the robot velocity on a given path. In addition, by default, when our robot is navigating a linear path at 20 cm/s of speed, the detection distance is set to 2 m. The distance is set to 1 m for a velocity of 10 cm/s, characterizing a circular path.

In this section, we detailed the main lines of our obstacle detection strategy and its implementation. However, as we will discuss in the next section, the effective detection of obstacles is performed by image processing, which is an important issue here to fulfill our seek for an accurate, reliable and real-time obstacle detection in a real-world environment.

2.4 Image processing

Previously we showed that any possible obstacle standing in the robot's front environment would show up as a vertical segment in the left region of the image captured by our sensor(refer to figure 2(b)). Here, we outline that the use of an optical filter to filtrate only the laser slit and to cut all visible lights enables our sensor to capture nearly binarized images, which consist of an uniformly black textured background with a white textured vertical segment, in case of obstacle presence. Doing so simplifies greatly the image processing to be conducted in this study in matter of difficulty, and mostly helps our seek for a real-time obstacle detection.

Based on such knowledge, the image processing performed here, consists simply of scanning from right to left, top to bottom the left region of any captured image, with the help of an horizontal line and confronts all met pixels with a constant threshold value. For a single image, it takes about one tenth of a second (0.1s)[1] to detect an obstacle presence in the robot vicinity. Therefore, as we scan our sensor in ten different directions ahead of the robot, it costs nearly a second to our sensor to scan fully and detect accurately any obstacle's presence in the robot's front environment.

3 Orienting dynamically the active vision sensor on the robot's path.

Once the mobile robot equipped with such sensor system, is navigating a defined path, particularly a circular one, the equipped sensor's orientation on the path becomes a matter of great importance here, since the robot must anticipatorily detect and avoid obstacles on the path. In this study, such navigation based-problem is solved by controlling the field scanned by our sensor. Such control is performed by directing

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[1] Vision Module CPU : Transputer T-805 (Clock:20MHz)

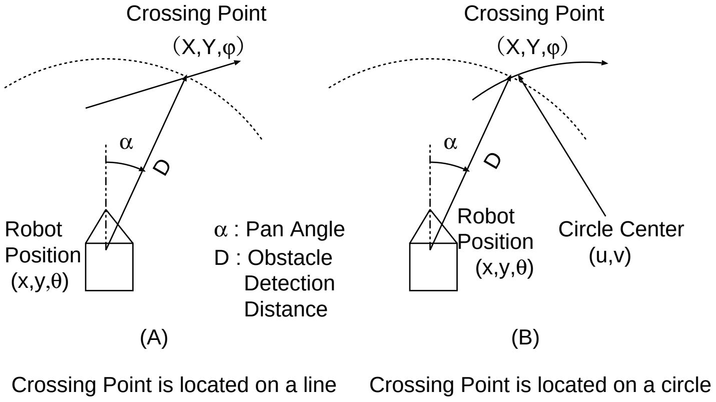

Figure 5: Pan orientation on the robot's path.

dynamically the meeting point of our sensor's components on the robot's path, thanks to the pan degree of freedom of the active vision sensor(refer to figure 3).

We define the robot's path as a succession of of lines and curves. And we basically control the field viewed by our sensor by computing dynamically the intersection of the path(line or curve) with a circle defined by its center, the robot's position on the path and its radius, the obstacle detection distance. Figure 5 shows such computational process and α represents the needed pan angle to redirect dynamically the active vision sensor on the forthcoming path.

4 Obstacle avoidance

4.1 Obstacle avoidance algorithm

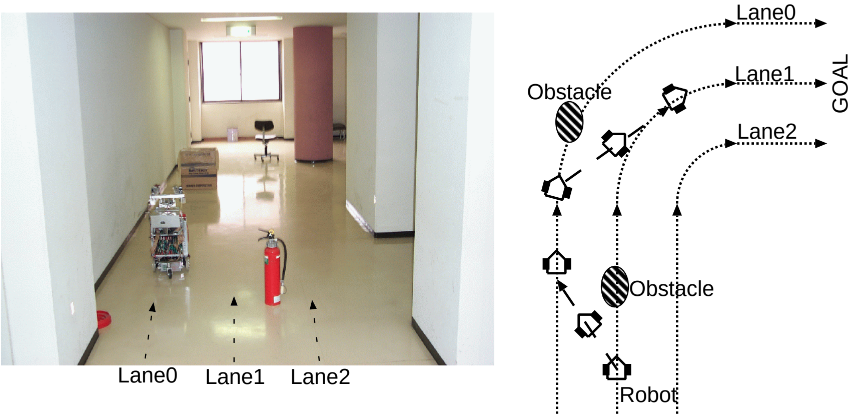

Figure 6: Obstacle avoidance action.

Once our mobile robot equipped with such sensor is able to detect stationary obstacles located on its path, the issue of avoiding those obstacles and continuing safely its navigation-based task naturally comes up. Historically, there are numerous obstacle avoidance methods adapted to a variety of sensors. Theoretically, we have methods based on avoiding obstacles accordingly to their shape, which demand a great environment knowledge of the sensors. Another major avoidance strategy is to avoid obstacles regardless of their shape and to consider for avoidance space only the navigable free space. Since the sensor developed for this work does not procure shape information

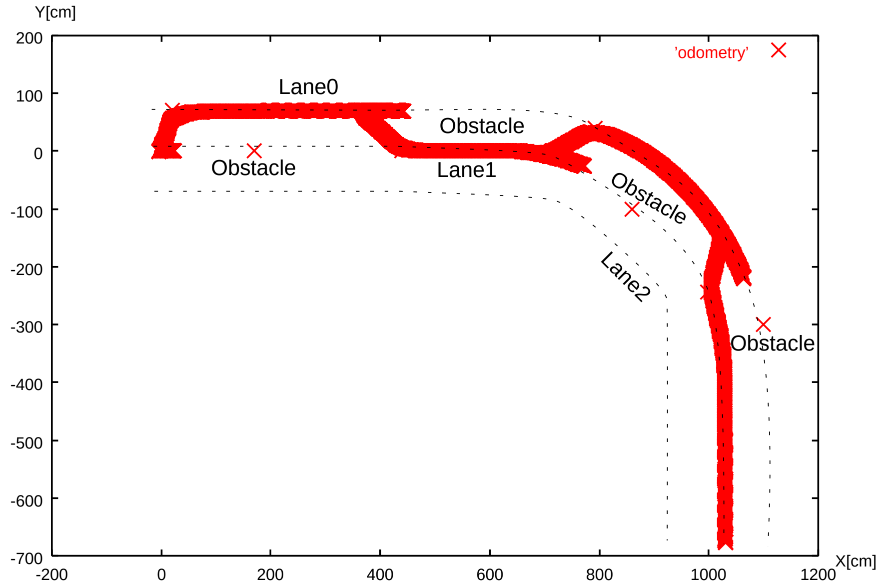

Figure 7: Experimental results of an obstacle detection and avoidance action in a corridor.

for the detected obstacles, we adapt the latter avoidance strategy to our sensor in an avoidance action taking place in an indoor corridor.

A view of such obstacle avoidance action is illustrated in figure 6. The basic and simple idea behind our obstacle avoidance algorithm is to enable our robot, after detecting objects obstructing partially its path to change dynamically its path in the free navigable space, in order to avoid obstacles, repeatedly until it reaches the goal of its navigation. For that purpose, we define offline a set of lanes parallel to the robot's path(center lane) and change dynamically the path on an adjacent lane when an obstacle is encountered on the path. This yields us to a simple to implement and effective obstacle avoidance action.

4.2 Experiments

For experiment purpose, we used a corridor(figure 6) having a width of 260 cm, in which our robot can navigate safely on three distinct lanes, parallel to each other. In this indoor environment, the robot's path is about 15 m of length and consists in a linear, circular and linear trajectory. We deliberately set 3-Dimensional obstacles on different lanes, and conducted our real-time obstacle detection and avoidance action in such an environment. During the experiment, the odometry of the robot was recorded and is plotted in figure 7.

Based on these results, we can deduce that an intelligent mobile robot equipped with the sensor developed in this study, is able to perform a reliable and real-time 3-Dimensional obstacle detection and avoidance in a real-world indoor environment.

5 Conclusion and future work

In this paper, the authors dealt with a real-time obstacle detection and avoidance method performed by an autonomous mobile robot using an active vision sensor and a vertical laser slit. After detailing our detection strategy and implementation of the developed sensor with our robot, we also introduced the basic algorithm of our avoidance method. We confirmed the originality of our approach with results of an obstacle avoidance experiment in an indoor corridor.

Reducing obstacle detection failures in well-lighted environment, due to the sunlight for instance, and improving our avoidance algorithm for moving obstacles are the topics of our future work.

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