A Purposive Strategy for Visual-Based Navigation of a Mobile Robot

Raquel Frizera Vassallo
Hans Jörg Schneebeli
Departamento de Engenharia Elétrica Universidade Federal do Espírito Santo
Vitória/ES BRAZIL
E-mail: {raquel,hans}@ele.ufes.br

José Santos-Victor
Instituto Superior Técnico &
Instituto de Sistemas e Robótica
Av. Rovisco Pais - Lisbon PORTUGAL
E-mail: jasv@isr.ist.utl.pt

Abstract

We address the problem of visual-based navigation of a mobile robot along corridors in indoors environments. The corridor lines are detected, and their vanishing point calculated. Its deviation from the central column of the image, the corridor lines slopes and the standard deviation of the vanishing point are used to control the angular velocity in order to keep the robot in the middle of the corridor. Such strategy exploits the structure of the environment to solve a specific navigation problem in a very robust manner.

1. Introduction

To make a robot to move inside a working area, it is necessary to use a sensorial system able to extract environmental information for controlling robot orientation and velocity, detecting obstacles, etc, thus making possible the robot to perform its tasks with some degree of autonomy.

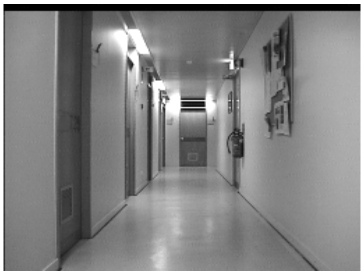
Vision is one of the most powerful human senses. Because of that, a significant research effort in robotics has been dedicated to the use of vision systems for robot navigation [1]. Earlier vision research were based on 3D reconstruction of the environment. Once extracting 3D information of the surrounding space is often a very computational demanding task, new vision approaches are being applied. Some of them exploit the structure of the environment for solving specific problems in a active way, known as active vision or active perception [4, 5, 6].

Following this idea, in this paper we use a priori knowledge about the 3D scene, together with a purposive definition of the navigation task to solve the problem. We apply an active vision strategy based on visual feedback to implement a robust and fast navigation control for a mobile robot inside corridors. A single camera located on the top of the robot platform is used to acquire images from a corridor during the robot motion. The objective is to keep the robot in the center of the corridor. It is assumed that there is a good contrast between the pavement and walls and that the pavement is planar. The basic idea is to use the contours of the corridor, as they appear in a 2D image, to generate a simple control algorithm.

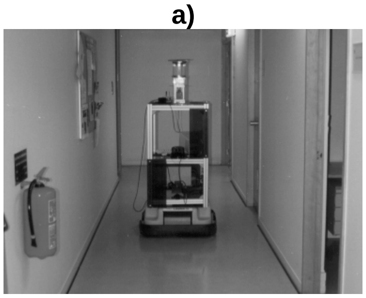
This approach is possible because of the 3D-world projection on a 2D image. The corridor guidelines are parallel in the 3D space. However, as they are projected on the image plane, they intersect at a point – the vanishing point. In terms of projective geometry, these lines intersect at a point in the line at infinity belonging to the ground plane [1,2]. If the camera orientation is kept constant relative to the guidelines, this point at infinity should be constant. Otherwise a control action must be taken to keep the vanishing point under fixation. One advantage of using this strategy is that there is no need to calibrate the camera parameters or position. The image presented in Figure 1 shows how the guidelines of a corridor appear to meet at a vanishing point.

The experiments described in this paper were made with a TRC Labmate, a mobile platform from HelpMate Robotics Inc.[7] that is also shown in Figure 1. The processing was done in grayscale images with 144x192 pixels, captured from a Sony camera installed on the top of the robot through an acquisition board model DT3852 of Data Translation. The RS-232 serial port was used for the communication between the built-in microprocessor-based driver system of the robot and a second onboard computer that carries out all the image and control processing.

This paper is organized as follows: Section 2 describes the navigation strategy; in Section 3, we characterize the corridor lines detection and the vanishing point calculation; in Section 4, we discuss the problem of heading velocity control; and, finally, in Section 5, we draw some conclusions and final remarks.



a)



b)

Figure 1. a)The edges of the corridor, that are parallel lines in 3D space, appear to converge as they recede towards the horizon in a 2D image. b) The robot used in the experiments, a TRC Labmate.

2. The navigation strategy

While the robot is moving inside a corridor, the navigation system must control the angular velocity based on the images acquired by the vision system. This is done by processing the images and determining the changes on the corridor lines vanishing point, which deviation from the central column of the image is used in the control law.

Before the robot starts moving, it initializes the image acquisition board and the communication interface between the robot and the onboard computer. After that, it starts a control loop defined by the following steps:

- Image acquisition;
- Edge detection for finding the corridor lines;
- Calculation of the vanishing point and its deviation from the central column of the image (both in pixels);
- Determination of the angular velocity command, using a PID controller driven by the vanishing point deviation from the central column of the image.

Because of the simplicity of the line detection process and the vanishing point determination, the task of image processing is guaranteed to be a fast one. This makes this strategy a very attractive one.

3. Line detection and vanishing point calculation

In this section, we describe the edge detection process for finding the corridor lines and the vanishing point calculation. To detect the corridor guidelines, the well known Sobel gradient operators are applied [1, 3] and some simple conditions are considered for selecting points of interest and detecting the lines. The procedure used can be described as follows:

- Apply the Sobel filters in the X and Y directions on the image;
- Select the points in the resulting image that have X-direction and Y-direction gradients above a certain threshold limit. This way, edge points lying on vertical or horizontal lines are discarded and only the points belonging to diagonal lines are selected;
- Separate in two binary images the points with positive gradient direction and the points with negative gradient direction. Each group corresponds to one of the two corridor lines;
- Erode each image with a mask corresponding to diagonal lines. This step eliminates part of the outliers in the selected point set;
- Use the remaining points to interpolate the equations of the corridor lines (see Figure 2). The fitting method used is the RANSAC method [9] and the equations of the two lines are defined as:

$$col = m_1 lin + b_1 \tag{1}$$

$$col = m_2 lin + b_2 \tag{2}$$

  where *col* is the value of the column and *lin* is the value of the line, both in pixels, in the image coordinates;
- Calculate the vanishing point by equating (1) and (2) and, after that, determine the deviation of the vanishing point from the central column of the image, both in pixels.

Figure 2. Line detection results

The final result of the image processing task above described is shown in Figure 2, where the detected lines and the selected points are superimposed on the original image observed by the camera.

4. The angular velocity control

The robot moves forward with a constant linear velocity that is independent from the heading control. Along the robot path in the corridor, the heading velocity will be controlled by a PID algorithm [7, 8]. The deviation of the vanishing point from the central column in the image will be defined as the feedback error. But, in this case, controlling the angular velocity means control both the robot orientation and position with only a single error signal. To overcome this problem, in addition to the deviation of the vanishing point, we also use the slopes of the corridor lines to determine the control gains. Another relevant aspect is that we propagate the uncertainty information from the edge localization errors all way till the determination of the vanishing point coordinates [10]. These uncertainty measurements, represented by the standard deviation on the vanishing point, and the lines slopes are used to modulate the control gains. Thus, the control law is given by

$$\omega_r = k_p \left\{ e(n) + k_d \left[e(n) - e(n-1) \right] + k_i \sum_{i=0}^{n} e(i) \right\} \quad (3)$$

with

$$k_p = 1.2(m_1 + m_2)\frac{5}{(1 + sdt)} \quad (4)$$

where k_p, k_d and k_i are the proportional, derivative and integral gains, modulated as mentioned before, *e(n)* is the deviation error from the central column, m_1 and m_2 are the lines slopes and *std* is the standard deviation of the vanishing point. The current control frequency is about 1 Hz.

This simple control law is chosen because it provides good results for the heading control problem, once the parameters are well adjusted, and it is not too demanding in terms of the onboard processing capability.

Figures 3, 4 and 5 show some of the results obtained while moving inside the corridors of the laboratory floor. It can be seen the robot trajectory recovered from odometry and the evolution of the deviation error, the standard deviation and the heading angle over time (in seconds). Figure 6 shows the whole trajectory of the robot at the laboratory floor reconstructed from odometry measurements.

It is important to say that the heading angles are measured counter clockwise. So, left turns are positive and right turns are negative. This orientation also apply to the angular velocity. The correct positions for robot turnings at the end of each corridor were determined by correlation of the acquired image with reference images previously saved.

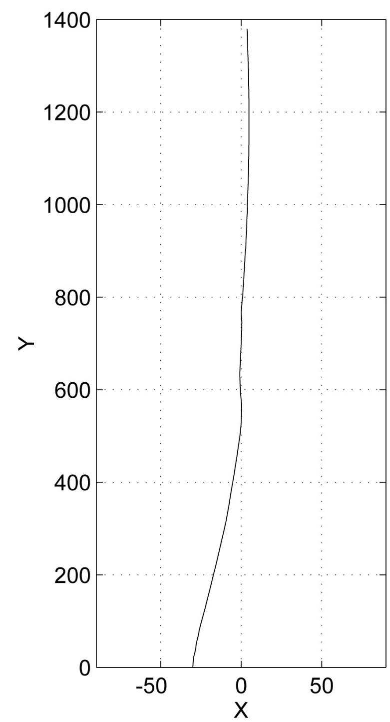


Figure 3. Robot trajectory recovered from odometry (cm).

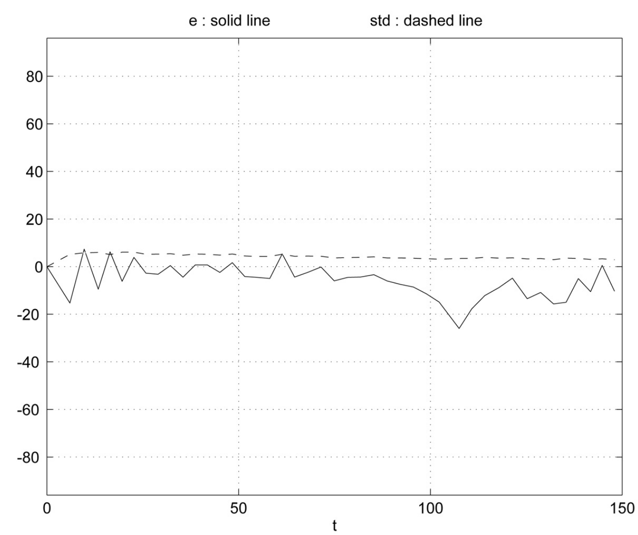


Figure 4. Deviation error and the standard deviation of the vanishing point (both in pixels).

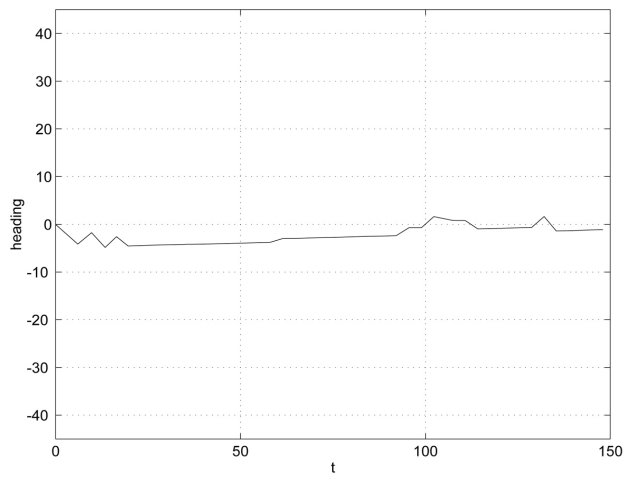


Figure 5. Robot heading during navigation (degrees).

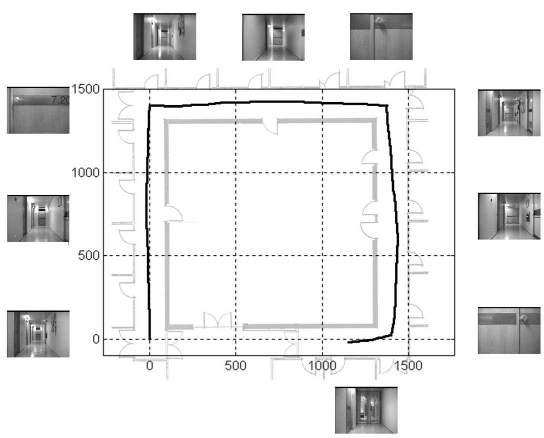


Figura 6. Robot trajectory recovered from odometry measurements (cm) along the laboratory floor.

5. Concluding remarks

We have addressed in this paper the problem of visual-based mobile robot navigation using a vision strategy based on a single camera and processing a sequence of grayscale images captured during the robot motion. The control goal amounts to detecting the corridor guidelines in the image and keeping their vanishing point centered. The results obtained till now are encouraging. The line detection and the heading control results show that exploiting the structure of the environment with a purposive definition of the navigation task represent a quite robust approach. Some problems remain to be solved and are out of the scope of this paper. Other paradigms and techniques are also being used, like using appearance based methods to monitor positions during navigation and to determine the moment to execute special tasks, like turns, entering doors, picking up objects, etc; Another aspect for future work is to use optical flow measurements to detect obstacles and calculate time to crash for the robot. These other approaches are left to be discussed in another paper or opportunity.

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