Reactive Robot Navigation: A Purposive Approach †

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1. Introduction

The term navigation refers to the capability of a system to move autonomously in its environment, by using its own sensors. The more specific term *visual navigation* is used for the process of motion control based on the analysis of data gathered by visual sensors. The field of visual navigation is of particular importance mainly because of the rich perceptual input provided by vision.

The problem of visual navigation has been traditionally treated without taking very much into account the environment of the robot, its body and the characteristics of the behavior that the robot is about to exhibit. Typically, monocular or stereoscopic visual systems are assumed and the effort is then focused in constructing a general representation of the environment that may thereafter serve the solution of any vision-related problem. During the last decade, a new vision paradigm has attracted the interest of the computational vision research community. In this paradigm, called *active and purposive vision* [1], vision is more readily understood in the context of the visual behaviors in which the system is engaged. Consequently, vision tries to explore those aspects of the world that are important to the system at a given point in time, instead of aiming at a general representation of the environment which, besides being extremely difficult to extract, it is probably also not needed.

In this paper, we describe a new method for visual robot navigation based on the principles of purposive vision. Thus, the aim of this research is not what vision can offer towards building a general-purpose world representation, but how the visual system of a robot can be designed in order to assist the robot in exhibiting particular behaviors. We assume a robot that can translate in the forward direction and rotate (pan) around its vertical axis. We aim at developing a vision based reactive navigation capability that enables a robot to navigate in indoor environments (long corridors, narrow passages), avoiding collisions with walls and obstacles. The term reactive is used to express lack of a particular destination that could be set by using maps of the environment, landmark recognition etc. Free space is defined based on the motor capabilities of the robot: since the robot moves on a plane, all 3D structures that do not belong to this plane can be potentially harmful if the robot crashes on them and are therefore considered as obstacles. Since the robot is about to "live" in indoor environments, it is expected to be able to handle situations where long corridors and narrow passages are encountered. It can be shown that difficulties arise when only central vision is used (i.e. a camera or a fixating stereo configuration at the direction of translation). Moreover, the use of cameras with wide field of view give rise to depth dependent geometric distortions that are difficult to correct. Instead, the proposed method employs a forward-looking camera for central vision and two side-looking cameras for sensing the periphery of the visual field (see for example the configuration in Fig. 3). By using such a camera configuration, the robot is able to perceive walls and obstacles that are immediately close to it. Moreover, the target behavior may be implemented by indirectly *comparing* structure information acquired by the left and right cameras instead of computing *precise* structure information. This approach is motivated by experiments [2] that study the navigational behavior of honeybees who possess eyes that are pointing laterally (at about 180 degrees). In these experiments, bees were trained to navigate along corridors towards a source of food. The bees were observed to navigate in the middle of the corridor. The behavior is based [2] on velocity information computed at the left and right eyes of the bee. In simple terms, if the bee is in the center of the corridor, it perceives the world as "leaving" its optical field with the same velocity in both eyes, while if the bee is closer to one of the sides of the corridor, it perceives it as moving faster.

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Figure 3: The KTH head with two extra cameras mounted on it for implementing peripheral vision.

Santos et al. [3] proposed the divergent stereo approach in order to exploit this finding in robots. They exploit visual information that is captured by two cameras with optical axes of opposite orientation that are mounted perpendicularly to the direction of forward translation. Our research has been carried out in the context of a general framework for vision-based robot navigation [4] and differs to the approach in [3] in several ways. First, peripheral cameras are not be placed in opposite directions because decisions on forward motion should not be influenced by “past" structure information. Moreover, it turns out that control is facilitated when the cameras are slanted. We also show how central vision (i.e. visual information acquired in the direction of the translation) can be used along with peripheral vision in order to simplify the problems to be solved.

2. Method description

It has been shown that by combining information that can be extracted from the two peripheral and the one central camera of the proposed configuration, the following function can be computed:

$$A = C\left(\frac{1}{Z_L} - \frac{1}{Z_R}\right). \quad (1)$$

In Eq. (1), A is a quantity that can be directly computed from the images acquired by the central and peripheral cameras. C is an unknown constant that depends on the characteristics of the body of the observer as well as its constant translational velocity. Finally, Z_L and Z_R are the depths perceived at the left and right peripheral cameras of the robot. A is equal to zero when the left and right cameras are in equal distances from the world and takes positive or negative values depending on whether the right camera is closer or farther from obstacles compared to the left camera. For the robot to move in the middle of the free space, A should be kept as close to zero as possible. Since A is a computable quantity, it can be used for controlling the rotational velocity of the robot, achieving this way the desired behavior.

The quantity A depends on the projection of the optical flow (u, v) along the intensity gradient direction (i.e. the perpendicular to the edge at that point) which is also known as *normal flow*. The normal flow is less informative than optical flow but can be computed robustly and efficiently from image sequences by just using differentiation techniques. Moreover, in contrast to the computation of optical flow, no environmental assumptions such as smoothness are required for normal flow computation. A is the algebraic sum of several functions of normal flow. These functions are computed by selecting normal flow vectors in particular directions, which depend on specific motion parameters.

3. Implementation issues - Experimental results

The experimental evaluation of the proposed method has been based on both simulation results as well as on results obtained by an on-line implementation of the method on a real robotic platform.

Simulations have been based on the KHEPERA simulator [5], which has been modified to simulate the central and peripheral cameras of a robot. The aim of the simulation experiments was to test the control law used to drive the robot. Thus the function A of Eq. (11) has been simulated and a simulated robot was set to navigate in a variety of worlds. Several experiments were conducted. Figure (2) shows the course of the robot during a sample run. It can be seen that the robot follows a smooth path among the various obstacles of the environment.

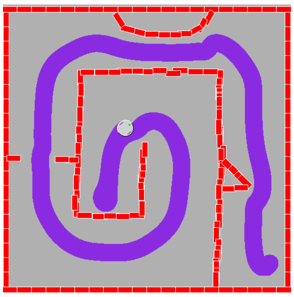
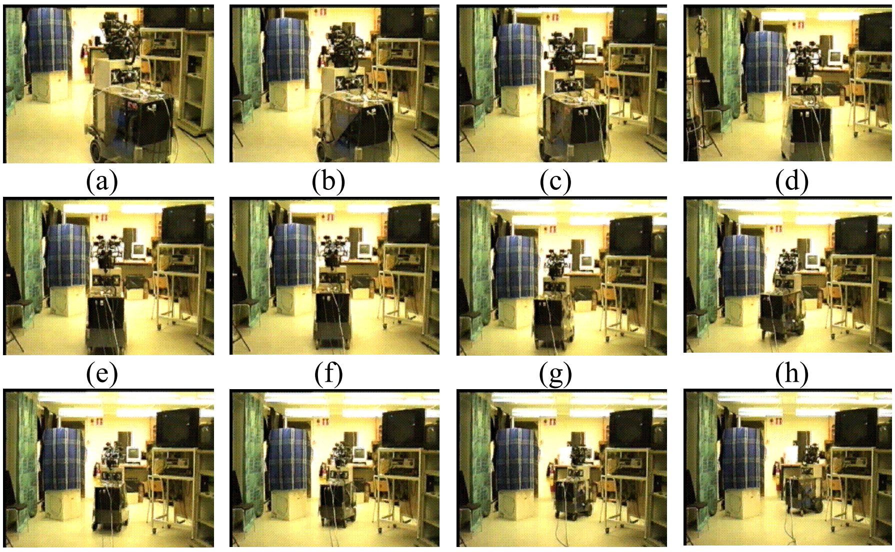


Figure 2: A run of the simulated robot.



(a) (b) (c) (d)
(e) (f) (g) (h)
(i) (j) (k) (l)

Figure 3: Snapshots of a navigation session

The simulation experiments are, of course, not capable of testing the performance of the method when real vision processes are employed. For this reason, an on-line implementation of the method has been prepared. The platform used was a LABMATE ROBUTER on which “Charlie”, the KTH vision head has been mounted. Two extra cameras were mounted on “Charlie” implementing the peripheral vision, while one of the two “Charlie” cameras was implementing central vision (Fig. 1). Various navigation scenarios have been tested in which the robot successfully managed to perform maneuvers in narrow passages. Due to space limitations, we present snapshots from one such experiment in Fig. 3.

4. Conclusions

A method has been proposed that enables a robot to navigate in free space based on a combination of central and peripheral vision. The method does not make strict assumptions about the environment, it requires very low level information to be extracted from the images, it produces a robust robot behavior and it is computationally very efficient. Results obtained by both simulations and from a prototype on-line implementation demonstrate the effectiveness of the method. Peripheral vision seems to be very useful for achieving certain behaviors and its combination with central vision seems natural and appears to be powerful. Future research work will investigate ideas on further exploiting combinations of central and peripheral vision.

References

[1] Y. Aloimonos, I. Weiss and A. Bandopadhay, Active Vision, I*nternational Journal of Computer Vision*",(2): 333-356,1988.
[2] MV Srinivasan, M Lehrer, WH Kirchner and SW Zhang, “Range Perception through Apparent Image Speed in Freely Flying Honeybees”, *Visual Neuroscience*, 6:519-535, 1991.
[3] J Santos-Victor, G. Sandini, F. Curotto and S. Garibaldi, ”Divergent Stereo for Robot Navigation”, Learning from Bees”.
[4] J. Dias, F. Bergholm, and P. Fornland, ``VIRGO Vision-based Robot Navigation Research Network, Overall Considerations and a Framework for Vision-based Navigation", Tech. Rep. ISRN KTH/NA/P--96/27--SE, Sept. 1996.
[5] Olivier Michel, Khepera Simulator 2.0, *User Manual, University of Nice, Sophia Antipolis.*