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An architecture for a VLSI sensory–motor system for obstacle avoidance

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Abstract

This paper presents a signal processing architecture for a sensory–motor system based on the smart sensor paradigm. The architecture is designed for an obstacle avoidance task by a mobile robot in an unstructured environment. Drawing inspiration from the field of behavior-based robotics, the development of the architecture is guided by an emphasis on the requirements of an obstacle avoidance behavior for a mobile robot. The architecture is simple enough for a smart sensor, but incorporates features which enable it to deal with realistic, unstructured environments. It differs from existing systems by using a special foveation scheme to facilitate the detection of real-world objects. From this, a motor control signal is produced by using a biologically inspired technique of aligning sensory and motor maps. The effectiveness of the architecture is explored through computer simulation, including an obstacle avoidance simulation in a 3D virtual environment.

Keywords: Obstacle avoidance; Autonomous robots; Smart sensors

1. Introduction

Autonomous robots which are meant to operate in remote or hazardous places will often need to perform visually guided behaviors in unstructured environments. Obstacle avoidance is an example of such a behavior. Traditional approaches to endowing robots with visually guided behaviors make use of conventional vision systems based on the combination of a camera and a digital processor. They place emphasis on constructing detailed models of the environment, from which appropriate actions are inferred. The processing is complex and computationally intensive and often leads to systems which are slow to react. The algorithms are also difficult to integrate into a monolithic system. Some of the traditional techniques to construct models, like stereo vision [1] and optical flow [2], also place strong constraints on the environment, such as the need for adequate texture or detailed features which the algorithms require to determine the depth of objects in the scene.

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In contrast to traditional systems using general-purpose computers or DSPs, smart sensors integrate optical sensing and signal processing at the pixel level. They have been shown to be successful in applications such as visual tracking [3,4]. For an obstacle avoidance task for autonomous robots, a VLSI system should be able to detect obstacles which have irregular shapes and complex textures in order to deal with unstructured environments. It should also be easy to interface to actuators without the need for extra microcontrollers to decipher its output. To achieve such a VLSI sensory–motor system, new architectures and strategies are needed.

Two common approaches to achieving sensory-motor functionality are to use correlation-based motion detectors [5,6] and gradient-based position trackers [7–9]. An example of the latter is a complete VLSI sensory–motor system reported by Maris and Mahowald [7]. Its architecture consists of a contrast sensitive retina followed by a winner-take-all operation to detect the location of the pixels with highest contrast. The system exemplifies the efficiency of pixel-level processing but is limited to detecting clear and consistent edges in a scene rather than complex, natural objects. Also, the chip area required for the operations is quite large.

Another example of a smart sensor that supports visually guided behavior was reported by Etienne-Cummings [6]. It makes use of a two level foveation scheme which allows both tracking and acquisition to be implemented on the same focal-plane. Similar to the first example, pixel-level edge detection is used, limiting the system to track or avoid only simple objects with well defined contours.

The sensory–motor architecture proposed in this paper uses a special foveation scheme to facilitate the detection of real-world objects for an efficient obstacle avoidance behavior in an unstructured environment. The basic concept and the structure of this architecture, as well as the simulation results will be presented in the following sections.

2. Sensory–motor architecture

2.1. Obstacle avoidance behavior

Inspired by the behavior-based approach to robotic control [10–12], the development of the architecture begins with a consideration of the required behavior. For an obstacle avoidance behavior, a robot should steer its body away from any stimulus which might signal that a significant object is in its pathway. As it moves, it should be orienting itself towards an open part of the pathway in front of it. The basic requirements are:

(1) real-world obstacles must be detected and located relative to the robot's body,
(2) the robot should steer to the left or right around the obstacle in a reactive manner.

If, as the first requirement suggests, only relative locations are needed, then actual positions in a coordinate frame need not be computed. The first requirement also suggests that obstacles do not need to be recognized or even resolved with much precision; they only need to be detected. In addition, resolving power does not even have to be the same for all parts of the scene. More distant parts of the scene do not need high resolution because in the distance only the detection of large objects is needed to make steering decisions. Space-variant or foveated sensing schemes have been shown to have these qualities, in both biological [13] and engineered systems [14]. Also, foveation has been shown to be useful in creating a frame of reference around a point in a scene, the point of fixation [15]. This 'fixation frame' can facilitate the localization of objects relative to the point of fixation. Thus, the first architectural decision for the sensory–motor system in this paper is that a foveated sensing scheme should be used. The particular scheme proposed in this paper is described below in Section 2.2.

The second requirement of the obstacle avoidance behavior suggests that for a typical wheeled robot, only a left/right orientation decision is needed to avoid an obstacle. This greatly simplifies the task of converting the visual signal to a motor signal. The fact that only a left/right decision needs to be taken can be exploited by aligning the map of the visual field (as represented on the sensor), with the center of the robot's body. If more obstacles are on the left of the visual field, then they are to the left of the robot's body and the robot should turn to the right. This is a simple alignment of a sensory map and a motor map, and is the second organizing principle for the architecture. An enhanced version of this alignment is described below in Section 2.3.