Deakin Research Online

This is the published version:


Available from Deakin Research Online:

http://hdl.handle.net/10536/DRO/DU:30044768

Reproduced with the kind permissions of the copyright owner.

Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

Copyright : 1994, IEEE
Insect Based Navigation and its Application to the Autonomous Control of Mobile Robots.

K. Weber, S. Venkatesh and D. Kieronska

Department of Computer Science, Curtin University of Technology, GPO Box U 1987 Perth 6001, Australia.
Email: weberk, svetha, dorota@cs.curtin.edu.au

Abstract

Giving robots the ability to autonomously move around in various real-world environments has been a major goal of AI (artificial intelligence) for quite some time. To this end it is vital for robots to be able to perceive their surroundings in 3D; they must be able to estimate the range of obstacles in their path.

Animals navigate through various uncontrolled environments with seemingly little effort. Flying insects, especially, are quite adept at manoeuvring in complex, unpredictable and possibly hostile and hazardous environments.

In this paper it is shown that very simple motion cues, inspired by the visual navigation of flying insects, can be used to provide a mobile robot with the ability to successfully traverse a corridor environment.

Equipping an autonomous mobile robot with the ability to successfully navigate real-world environments (in real-time) constitutes a major challenge for AI and robotics. It is in this area that insect based navigation has something to offer.

1 Introduction

Clearly for autonomous robots to be able to successfully navigate in unfamiliar environments they must be able to autonomously perceive their environment. For short-range navigation it is vital that they be able to detect and avoid obstacles in their path in a cost-effective (real-time) way, both for survival and safety. It is also very desirable to be able to detect and avoid dynamic objects, which are not uncommon in real-world environments.

Among the sensors used for robots, visual sensors probably provide the richest source of useful (navigational) information about the surrounding three-dimensional environment. However, visual sensors are also the ones that are the most computationally expensive.

One possible solution to the problems of vision, is that of employing specialized hardware for navigation, such as laser rangefinders, sonars, and inertial navigation systems. However, the addition of this equipment is quite expensive and as [1] note, even sophisticated inertial navigational systems accumulate positional error requiring periodic correction. Qualitative techniques hold the potential to replace expensive numerical (quantitative) computations and models (with often unnecessary precision) by a simpler process that reasons about the important properties of a scene.

One approach when trying to construct a machine to do some particular task (that is known to be done by another “machine”) is to investigate and try to copy others who do it. However, trying to copy how humans see is not an easy task. Perhaps we should look at how simpler animals, such as insects, solve the problems of navigating in uncontrolled environments. After all, they do not seem to need sonars or laser range finders to successfully manoeuvre between static and dynamic objects.

Flying insects are examples of autonomous mobile creatures within nature. Despite their relatively simple nervous systems, flying insects are capable of amazing aerobatics. Being able to move quickly in highly complex, hazardous and unpredictable environments, insects show that they have solved some of the real-time vision and navigation problems which have proved themselves difficult to achieve in an autonomous mobile robot (e.g. collision avoidance). Given their small size and relatively simple nervous systems it seems likely that they employ quite simple strategies and mechanisms in their perception of, and navigation within, the real world. It would certainly be an advantage to copy these strategies for robot navigation.

Recent behavioural evidence concerning the behaviour of flying insects is now showing what sort of visual cues flying insects use to achieve their navigational prowess [8].

The main purpose of this paper is to show that very simple motion cues, inspired by the visual navigation of flying insects, can be used to provide a mobile robot with the ability to successfully traverse a corridor environment.

2 Background

Animals navigate through various uncontrolled environments with seemingly little effort. Flying insects, especially, are quite adept at manoeuvring in complex, unpredictable and possibly hostile and hazardous environments. For example, a fly is quite good at avoiding being swatted by a human hand.

By their very behaviour flying insects, such as flies and bees, show that they perceive the world in three dimensions. However, the characteristics of their compound eyes raise questions about exactly how they are able to do this. Unlike vertebrates, insects have immobile eyes with fixed-focus optics, implying that the range of an object cannot be
inferred by stereopsis or the refractive (focusing) power required to bring it into focus on the retina [8].

Considerable evidence now suggests that moving insects are able to infer the ranges of objects from the apparent motion of their images across the eye (i.e. motion parallax). A potentially rich source of range information is the optic flow experienced by the eye when in motion; the closer a stationary object is, the higher its apparent velocity across the retina. Thus, if an insect knows its speed of motion, it can estimate the range of an object by its apparent angular velocity [6][7][8].

The range \( r \) of an object can be inferred from its angular velocity \( w \), its relative angle \( x \), and the velocity \( v \) of the eye [4] (see figure 1).

\[
 r = \left( \frac{v}{w} \right) \sin (x) \tag{2.1}
\]

![Figure 1 - Range from Apparent Velocity](image)

It is thus proposed that moving insects perceive the distances of objects in terms of the speeds of their images on the eye (the higher the speed the closer the object) [7].

There is much experimental evidence that insects use visual motion to estimate range. Furthermore, it has long been recognized that insects can easily distinguish between the real motion of an object, and the apparent motion of a stationary object (resulting from egomotion). This is despite the fact that, in either case, the image of the object moves relative to the background. Perhaps optic flow is also used to compute the “expected” apparent motion of a stationary object and to distinguish it from real motion (i.e. that of a dynamic object) when it occurs [8].

Flying insects, such as honeybees, use optic-flow cues to estimate the distances of surfaces, discriminate between objects at different distances, track moving targets, land on a contrasting edge, and distinguish an object from a background [6][7][10].

Bees also use the (peripheral) optic flow (apparent angular velocities) experienced by their eyes to navigate around obstacles and fly a straight equidistant path between obstacles. It has been shown ([6][7]) that flying honeybees balance the speeds of image motion on the two eyes, to maintain “correct” flight trajectories; to centre their flight paths between obstacles. For instance, when flying down a tunnel, bees try to maintain an equidistant flight path between the two walls by balancing the apparent angular speeds of the two walls (or equivalently, the speeds of the retinal images on their two eyes).

3 Copying Bee Behaviour

Inspired by the way honeybees use apparent motion (i.e. velocity parallax) in their navigation, we have looked at trying to use the same simple cue to provide a mobile robot with the ability to successfully navigate along a corridor environment. As will be shown the model robot is able to traverse a (possibly dynamic) corridor environment and avoid simple obstacles by observing the apparent velocities of points (contrasts), seen by two laterally pointed cameras.

3.1 Similar Work Done

In the past few years there have been a few similar implementations in the same vein: they also are inspired by the navigational behaviour of honeybees.

One such implementation is by [5]. The experimental setup is based on a mobile platform with two cameras pointing laterally in opposite directions. When the robot is in motion, the average image velocity seen by each camera is compared (in real time), and used to control the robot’s direction and velocity. No attempt is made to compute range in metric terms (i.e. distance); range is measured in terms of image velocity. The robot moves forward at approximately 8 cm/s.

Another mobile robot inspired by the centring behaviour of bees is by [2]. It uses low resolution motion vision over large fields of view to steer between obstacles. The system uses two receptive fields, one for each of the left and right peripheral fields of view. This is implemented with a single, forward facing, wide-angle (115 degree) camera. The receptive fields of view are essentially just the left and right thirds of this frontal view. The response of each field is the largest optical flow in the left and right fields of view are then compared (in real time) to steer between obstacles. However, this implementation does not attempt to compute range for objects in the image. The optic flow processing in each field is implemented in two parts: first, gradient-parallel flow is estimated (using local neighbourhood operations); then the maximum flow is identified by examining a histogram of the flows.

3.1.1 Improvements

There are several deficiencies in the implementations just described (see [9]), which have been addressed here:

1. The two cameras are more forward facing, enabling a better view of upcoming obstacles and the changing dynamics of the corridor. However, the apparent velocities observed are appropriately “weighted” by the relative angle of the apparent motion.
2. The system takes robot rotation into account when calculating apparent motion. This is crucial for the robot to be able to change direction as it moves, especially when the robot uses the cameras to look further forward rather than simply to the side. The rotational component becomes increasingly more significant as the motion approaches the FOE (focus of expansion). The perceived motion can even reverse direction when approaching the FOE.

3. The apparent velocities observed by each camera are not averaged. Instead, the most important (i.e. closest) objects are used exclusively in the determination of course control (i.e. navigation). Actual ranges are calculated for this purpose, using the known velocity of the robot.

3.2 Simulation

The basis of the simulation is the modelling of the robot’s motion and the analysis of the images acquired from two laterally pointed cameras. Raytracing is used to provide the images that would be seen by the cameras. The simulated environment (i.e. the corridor) is simply made up of textured walls. (The simulations were run on Sun SPARC workstations).

Since the robot’s motion is only in the horizontal plane there is no vertical motion and so a single row of horizontal pixels in the images can be analyzed. The typical corridor environment has vertical edges which can be detected by a single row of pixels in the crossection of the vertical edge (e.g. a door). It is a simple matter of looking at more rows if deemed necessary. However, for the purpose of testing the system/theory one row of pixels was quite satisfactory.

3.2.1 Robot Setup

The simulated robot is based primarily on the real mobile robot which was used for some (limited) real-world testing (see section 3.4). The robot moves via two drive wheels, located at the front on either side of the robot. These drive wheels are controlled independently and move with a specified velocity. Robot turning is achieved by simply having one wheel driving the robot at a higher velocity than the other.

3.2.2 Methods For Apparent Velocity Calculation

Two basic methods for measuring the velocity of apparent motion have been investigated: 1D optical flow ([3][5]) and a simple differencing and tracking method. With both of these methods the motion is calculated from sequences of 5 images which are grabbed at video rate (25 frames per second).

Although both of these methods were investigated for the acquisition of the motion information, the 1D optical flow method was found to be lacking the required accuracy. Thus, the results presented in this paper were obtained using the tracking method only.

3.2.3 Course Correction

The method of calculating range is based on equation 2.1.

The basic camera setup for the robot is quite simple. In the simulations the cameras had an 85 degree field of view and were pointed 42.5 degrees forward of side-looking. Looking forward gives a much better view of the upcoming environment, especially obstacles. However, this still leaves a 10 degree blind spot directly in front of the robot.

The course correction strategy used here is also quite simple. Basically, the robot heads for the equidistant point between the object with the smallest relative angle and the object closest to this object but on the opposite side of the corridor.

Consider the situation in figure 2 for example. The object with the smallest relative angle is object 1 (theta is smaller than alpha). The object that is closest to object 1 (but on the other side of the corridor) is then object 2. The robot then heads for the equidistant point between these two objects (as indicated by the arrow). Given the ranges of these perceived objects (e.g. r1 and r2), again calculated from apparent velocity, and their relative angles it is a relatively simple matter of calculating this new target course.

3.3 Results

Figures 3-4 show the model robot traversing various corridor environments. The leading edge of the robot is shown as it progresses up to corridor. The corridor is 2m in width and the robot travels at approximately 20cm/s. Figure 3 shows the behaviour in a straight corridor with simple obstacles. Figure 4 shows the behaviour of the model robot in a non-straight corridor. For further results see [9].

3.4 Real-World Implementation

Some limited real-world experiments were also conducted with promising results.
The experimental setup is based on a mobile robot platform with two video cameras mounted on top, pointing laterally to each side. The robot is connected (via a communications cable) to a Sun workstation which performs the necessary real-time computations and issues the movement commands.

The robot simply moves via two drive wheels, located at the front on either side of the robot. These drive wheels are controlled independently and move with a specified velocity. Turning is achieved by simply having one wheel driving the robot at a higher velocity than the other. The robot has an on-board (IBM compatible) PC which accesses and controls the hardware (i.e. performs the low-level wheel movement commands).

With regard to the real-world environment there was really only one compromise that had to be made: the corridor in which the robot was being tested did not contain enough contrasting edges and so some were added. This problem was compounded by the limited field of view offered by the video cameras (30 and 40 degrees).

Due to the hardware limitations, tests were only conducted using side-looking cameras. The control strategy used was therefore also much simpler. The robot simply turns at a rate that is proportional to the difference in range between the two sides of the corridor. The robot thus slowly gravitates toward the centre of the corridor.

Although the robot could only be run in a 5m section of a straight corridor (due to its umbilical cord) the test results were quite promising. The robot moves at approximately 20 cm/s.

5 Conclusion

It has been shown that very simple motion cues, inspired by the visual navigation of flying insects, can be used (i.e. provide enough information) to provide a mobile robot with the ability to successfully traverse a corridor environment.

Specifically, we have shown the possibility of equipping a mobile robot with the ability to successfully navigate a corridor environment (in real time) using the bees' navigational strategy of observing apparent velocity (i.e. velocity parallax). The robot is able to traverse a corridor environment (both straight and non-straight) and avoid simple obstacles by observing the apparent velocities of points (contrasts), seen by two laterally pointed cameras.

Providing an autonomous robot, operating in the real world, with a real-time navigational control system constitutes a major challenge for AI and robotics. It is in this area that insect based navigation has something to offer. As has been shown, quite good behaviour can be achieved from very simple strategies and mechanisms. Clearly there are benefits in examining biological systems.

6 References


