Schriftenreihe

Manfred Beneder (ed.)

robots@aec.at

Proceedings on the 1st Workshop on Teleoperation and Robotics Applications in Science and Arts

June 6th 1997

Ars Electronica Center Linz, Austria

Contents

A PROPOSAL FOR A BEE-INSPIRED VISUAL ROBOT NAVIGATION

G. Bianco, R. Cassinis, A. Rizzi, S. Scipioni [1)]

Abstract

A proposal for a visual navigation method inspired by insect behaviours is presented. Starting from the bee visual system, a three-phase model is described and different methods and strategies to exploit these phases are presented. Some of them has been implemented and tested by computer simulations. The obtained results have proven the interest of this entomological approach.

1. Introduction

Entomological studies about social insects (bees, ants, etc.) have discovered some mechanisms of visual navigation and landmark usage that can be useful in robotics [13, 14].

In order to accomplish various tasks, several insects use vision as the primary data source. Despite their neural system is relatively small and not very sophisticated, they are able to navigate, orient themselves, recognise landmarks and perform other tasks that involve a lot of cortical areas in human vision system. Studies about bee vision system can be a good approach to realise a vision system for autonomous robot guidance. An overall model taking into account the entire set of possible navigation tasks has not yet been developed because of the large amount of biological components involved in mobility tasks [18], but parts of it have already been studied [20] [16]. Beginning with some physiological characteristics (paragraph 2) of bee vision system and considering some interesting bees' behaviours concerning landmarks, a three-phase visual navigation model is introduced (paragraph 3 and 4.

[1)] Dept. of Electronics for Automation - University of Brescia, Via Branze 38, I-25123 Brescia - Italy

2. Physiology and behaviour of the bee

Most of the physiological aspects of bee vision system are still unknown, even if almost all of its biological characteristics have been measured.

The compound eye of a bee is a "spherical" array of about 5000 elementary eyes, called '*ommatidia*', each of them has got a complete focal system composed by a lens, a sensible element and a focal length [7].

Bee's visual spectrum spread from 300 nm (ultra violet) to 650 nm (bee-purple). They have a tricromatic vision with peaks at blue (450nm), yellow (550nm) and ultra violet (300nm) [6]. So bees cannot perceive pure red and, even if few types of flowers are red, usually they have high reflectance component in the ultraviolet (i.e. the poppy).

Bees have a divergent vision system: the convergent vision field is 28° down, 90° back, 40° in front and the whole vision field is 202°÷250° front-back and 100°÷125° top-bottom [9]. So they cannot infer the object distance by triangulation: they use other system such as the optical flow.

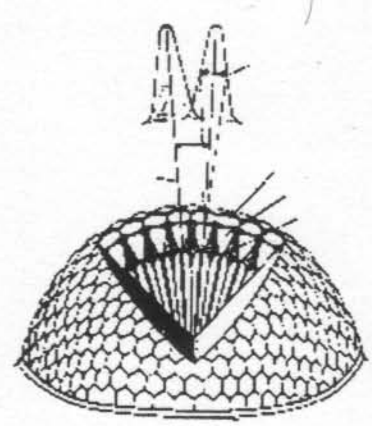

Figure 1 – Each ommatidia collects the light by a Gaussian function

The flickering frequency is about 200÷300 Hz [12] so they can perceive movements rapidly.

The ommatidial angle is the visual field of single ommatidia: its value varies according to the regions of the compound eye and different scientists estimate it in different ways. According to Baumgärtner it is about 0.97°÷ 4°, according to Portillo about 1.4°÷ 2.8° [6]. The intensity distribution could be represented by a gaussian function of the incident angle of light into a single ommatidia (figure 1) [19].

Starting from these data and from previous works [16] some statements about functional/computational characteristics of bee vision system (considered in a visual navigation model) can be expressed. Some of the following aspects of the bee visual system can be useful for a visual navigation model [20]:

- Bees perceive a 3D-color space.
- Bees memorise a nearly unprocessed retinal image of the goal location
- Bees can infer the speed at which prominent edges move over their eyes

Experiments on bees suggest that these fix the location of landmarks surrounding a place by storing a sort of snapshot of the landmarks taken from that place. The snapshot taken does not encode explicitly any information concerning distance; however, the position of each landmark is labelled by its compass bearing [4].

This use of landmark is quite different from the classical one, where a landmark has fixed and known position. In fact, classically landmarks are distinct features that an agent can recognise from its sensory input; those features are important for successive orientation or navigation actions [2].

Social insects use landmarks as one of two possible methods to return to specific places, namely: *dead-reckoning* and *near-by landmark* navigation [15].

Bees exploit the dead-reckoning phase, for example, to go toward a zone for foraging; in this case, information about the module and the orientation of the navigation vector is given by the dance of the nestmates. The near-by landmark method is used when the dead-reckoning does not have the degree of precision wanted and in general bees use it for homing.

An interesting model introduced to explain how bees exploit the near-by landmark phase navigation has been proposed by Cartwright and Collett in 1983; the results of this model, simulated with a computer, closely approximates the actual behaviour of bees.

However, a more complete navigation model, inspired by bees, really has to take into account three different phases:

- *Near-by landmark navigation phase:* the differences in position and in shape between the landmarks of the two images drive bees toward the goal [20].
- *Matching phase:* bees compare the stored snapshot of the area surrounding the goal with the actual perceived image [3];
- *Learning phase:* bees choose the most reliable landmarks for positioning by learning colour, apparent shape and orientation of them [8];

3. Near-by landmark navigation phase

A mobile agent needs navigation capabilities in order to reach, through a certain path, a definite area in the space called goal. Therefore, some data are necessary as, for instance, the goal spatial co-ordinates or some identifiable object in his proximity.

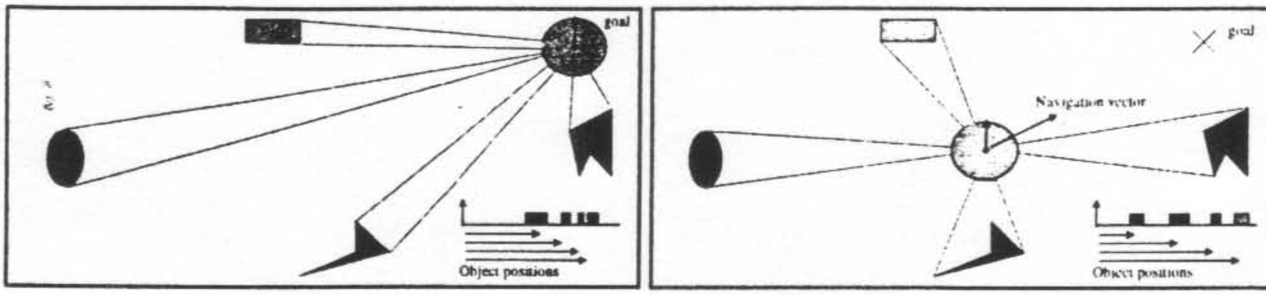

Figure 2 – Learning landmarks set (left) and actual landmarks set (right)

Using all the information extracted from the current location and in the learning phase (figure 2), mobile agent computes (an approximation of) the direction and the distance to the goal from its position.

In general, the learning phase is exploited only once whereas more localisation and approach phases are needed from the starting position to the goal.

For each matched landmark two vectors are computed; the first considers the orientations ϑ (normalised between 0 and 2π) of the same landmark in the two images (Learning and Actual):

$$\left|\bar{V}_i^r\right| = k \cdot (1 - P_{angle}(\vartheta_i^L, \vartheta_i^A))$$

$$\arg(\bar{V}_i^r) = \begin{cases} \vartheta_i^A + \dfrac{\pi}{2} & \text{if } \vartheta_i^L \le \vartheta_i^A \le \vartheta_i^L + \pi \text{ or } \vartheta_i^A \le \vartheta_i^L - \pi \\ \vartheta_i^A - \dfrac{\pi}{2} & \text{if } \vartheta_i^L - \pi < \vartheta_i^A < \vartheta_i^L \text{ or } \vartheta_i^A > \vartheta_i^L + \pi \end{cases}$$

The second vector considers the (apparent) sizes ρ of the same landmark in the two images:

$$\left|\bar{V}_i^c\right| = k \cdot (1 - P_{dim}(\rho_i^L, \rho_i^A))$$

$$\arg(\bar{V}_i^c) = \begin{cases} \vartheta_i^A & \text{if } \rho_i^L \le \rho_i^A \\ \vartheta_i^A - \pi & \text{if } \rho_i^L > \rho_i^A \end{cases}$$

The final navigation vector is given by:

$$\vec{V} = \sum_{i=1}^{N} (\vec{V}_i^r + \vec{V}_i^c)$$

P_{angle} and P_{dim} represent probability functions whose definitions are given in the following paragraph.

4. Visual matching phase

A landmark of the actual image has to be joined to a landmark of the learning image. If ϑ, ρ and λ represent respectively the orientation, the (apparent) dimension and the colour of the considered landmark *i*, the correspondence between landmarks in learning and actual image is given by a probability of:

$$P(\text{Landmark i} = \text{Landmark j}) = A * P_{color}(\lambda_i^L, \lambda_j^A) + B * P_{dim}(\rho_i^L, \rho_j^A) + C * P_{angle}(\vartheta_i^L, \vartheta_j^A)$$

Where A, B, C are positive coefficients with A+B+C=1; landmark *i* in the learning image matches landmark *j* in the actual image when the couple *(i,j)* has the greatest probability value; P_{angle}, P_{dim} and P_{color} are given by:

$$P_{color}(\lambda_i^L, \lambda_j^A) = \begin{cases} 1 & \text{if } \lambda_i^L = \lambda_j^A \\ 0 & \text{otherwise} \end{cases}$$

$$P_{dim}(\rho_i^L, \rho_j^A) = \begin{cases} 1 & \text{if } \rho_i^L = \rho_j^A \\ 1 - \left| \dfrac{\rho_i^L - \rho_j^A}{\max(\rho_i^L, \rho_j^A)} \right| & \text{otherwise} \end{cases}$$

$$P_{angle}(\vartheta_i^L, \vartheta_j^A) = \begin{cases} 1 & \text{if } \vartheta_i^L = \vartheta_j^A \\ 1 - \dfrac{\min(\vartheta_j^A - \vartheta_i^L, \ 2\pi + \vartheta_i^L - \vartheta_j^A)}{\pi} & \text{otherwise} \end{cases}$$

The probabilistic matching can be computed in three different ways:

1. Each match is considered in the navigation formula
2. Only matches whose probability is higher than the mean value are considered in the

navigation formula

3. Only matches whose value is greater than a given value are considered in the navigation formula

Figure 4 (taken by the simulator environment) shows the differences between the above techniques (the bee is in the same position). Numbers standing under each landmark represent the probability of the match; each probabilistic approach computes a specific navigation vector (cross near the bee in the figure).

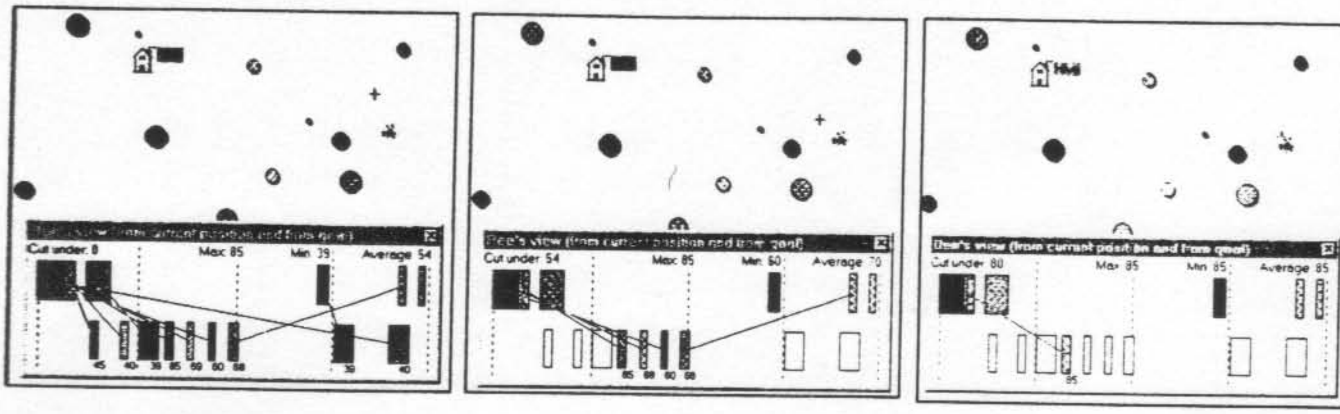

Figure 3 – Different probabilistic matching approach: every landmark is considered (left), only those above the mean value (middle) and only those greater than a given value (right)

5. Learning phase

Visual navigation is feasible if, in a preliminary phase, the mobile agent acquires all the necessary data about the goal. In fact, the use of landmarks presupposes answers to two questions:

1. How can a landmark be chosen?
2. How can a chosen landmark be recognised in successive navigations?

Some interesting answers could be found in the *Turn Back and Look* (TBL) phase fulfilled by bees [8]. Landmark distance is learned during the first departures from a place through this phase and both colour and apparent dimension of the landmark are learned subsequently. Distance information is essential in order to segment the snapshot between near and far landmarks. Other justifications concerning the aim of TBL could be found in [5] asserting that bees consider landmarks differently: the closer to the target, the more important the landmark is. In fact, bees need (indirectly) information about landmark distance because they can define the goal position more accurately: the closer a landmark is to a goal, the more precisely it identifies the position of the goal.

5. Conclusions and perspectives

Some considerations about physiological and behavioural issues concerning bees have been expressed; thanks to previous considerations a visual navigation model has been introduced.

In order to test the various parts of the introduced model, has also been implemented a simulation framework.

New theoretical issues, as the probabilistic matching, have also been considered.

Several researches are still in progress, respectively:

- The simulator must consider real images: now it considers uni-dimensional images grabbed with a 360° eye.
- The Turn Back and look phase must be implemented and tested: optical flow and image segmentation must be considered. At the end of the learning phase the matching and the near-by-landmark phases could be performed in a more efficient way.

Simulator tests have shown good results and have proven that the "entomological" approach could be taken into account for developing autonomous robots.

6. Bibliography

[1] G. BIANCO, R. CASSINIS, A. RIZZI, N. ADAMI, P. MOSNA, *"A bee inspired robot visual homing method"*, will be presented in Eurobot97, Brescia, Italy, 9-11 October 1997.

[2] J. BORENSTEIN, H. R. EVERETT, L. FENG, *"Where am I? Sensors and Methods for Mobile Robot Positioning"*, University of Michigan, 1996.

[3] B. A. CARTWRIGHT, T. S. COLLETT, *"Landmark Learning in Bees"*. J of Comp Physiol A 151, pp. 521-543, 1983.

[4] B. A. CARTWRIGHT, T. S. COLLETT, *"Landmark Maps for Honeybees"*, Biol. Cybern. 57, pp. 85-93, 1987.

[5] K. CHENG, T. S. COLLETT, A. PICKHARD, R. WEHNER, *"The use of visual landmarks by honeybees: Bees weight landmarks according to their distance from the goal"*. J of Comp Physiol A 161, pp. 469-475, 1987.

[6] T. H. GOLDSMITH, *"The physiology of insecta"*, Academic Press, New York, Vol. I, pp. 397-462, 1974.

[7] G. A. HORRIDGE, *"The compound eye and vision of insects"*, Clarendon press, Oxford, 1975

[8] M. LEHRER, T. S. COLLETT, *"Approaching and departing bees learn different cues to the distance of a landmark"*. J Comp. Physiol. A 175, pp. 171-177, 1994.

[9] NAZOKHIN, PORSHNYAKOV, *"Insect Vision"*, Plenum press, New York, 1969

[10] S. NEGAHDARIPOUR, *"Multiple interpretation of the shape and Motion of Objects from Two Perspective images"*, IEEE Trans. on P.A.M.I., vol. 12, no. 11, pp. 1025-1039, 1990.

[11] A.N. NETRAVALI, B.G. HASKELL, *"Digital Pictures-Representation and Compression"*, Plenum Press, New York, 1988.

[12] K. D. ROEDER, *"Insect physiology"*, Wiley, pp. 488-522. 1958.

[13] J. SANTOS-VICTOR, G. SANDINI, F. CUROTTO, S. GARIBALDI. *"Divergent stereo for robot navigation: learning from bees"*. IEEE Computer Society Conference on Computer Vision e Pattern Recognition. New York City, June 15-18, 1993.

[14] J. SANTOS-VICTOR, G. SANDINI, F. CUROTTO, S. GARIBALDI. *"Divergent stereo in autonomous navigation: from bees to robots"*, Int. Jour. of Computer Vision. 14, 159-177, Kluwer Academic Publishers, Boston, 1995.

[15] M. SNYDER, *Personal Communication*, University of Alberta, Canada, 1987.

[16] M. V. SRINIVASAN, M. LEHRER, S. W. ZHANG, AND G. A. HORRIDGE. *"How honeybees measure their distance from objects of unknown size"*. J of Comp Physiol A 165, pp. 605-613, 1989.

[17] Y. T. TSE, R.L. BAKER, *"Camera zoom/pan estimation and compensation for video compression"*. SPIE Image Processing Algorithms and Techniques II, vol. 1452, pp. 468-479, 1991.

[18] B. A. WANDELL, *Foundations of Vision*, Sinauer Associates Inc. Publishers, Sunderland, Massachusetts (1995)

[19] R. WEHNER, *"Information processing in the visual systems of arthropods"*, Springer-Verlag, Berlin-Heidelberg-New York, 1972.

[20] T. WITTMAN, *"Insect navigation: Models and Simulations"*. Tech. rept. 02/95. Zentrum fur Kognitionswissenschaften, University of Bremen, 1995.