An Insect-Based Approach to Robotic Homing

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Abstract

Many animals, including insects, successfully engage in visual homing. We describe a system that allows a mobile robot to home. Specifically, we propose a simple extension to our original homing scheme which significantly improves its performance by incorporating a richer view of the environment. The addition of landmark apparent-size cues assists homing by providing a more robust homing vector as well as providing a simple and effective method of reinforcing landmark avoidance.

The homing algorithm allows a mobile robot to incrementally home by moving in such a way as to gradually reduce the discrepancy between the current view and the view obtained from the home position. Both simulation and mobile robot experiments are used to demonstrate the feasibility of this approach.

By matching the bearings of features extracted from panoramic views and using a vector summation technique to compute a homing vector, we are able to provide a simple, parsimonious, and robust robotic homing algorithm.

1. Introduction

Getting robots to navigate autonomously has proven to be a difficult task. It is intriguing, then, that small living organisms, such as insects, have evolved effective solutions to this problem despite having relatively simple nervous systems and restricted processing capacity. Insects may well be described as the ultimate miniature machines.

Insects, particularly hymenopterans such as bees and certain species of ants, rely heavily on visual cues for homing [4]. Similar principles could conceivably be applied to the design of navigational strategies for a planetary rover that may be deployed to explore unknown territory over the course of an entire day, and to return to its 'home base' at nightfall to recharge batteries or transfer data.

In this paper, rather than follow traditional anthropomorphic or engineering-based approaches, we explore a navigational strategy that is inspired by insect ethology. The underlying rationale is the expectation that the parsimonious solutions offered by insects can be usefully incorporated into algorithms for robot navigation. We thus present a simple, robust strategy for robotic homing, inspired by the visual homing behaviour of bees and ants.

2. Background

A large number of experiments (see [4] for a review) have shown that many insects are able to 'home in' on a specific location, such as a nest, by using visual cues provided by landmarks in the vicinity. This ability is developed most highly in central place foragers, like bees [2, 1] and ants [9]. The insect behaves as though it is striving to 'home in' by moving in such a way as to maximise the match between the current retinal image and a 'snapshot' of the panorama as seen from the goal, acquired on an earlier visit [2, 3]. In this way the insect is continually and locally guided by the desire to reduce this discrepancy between current and home snapshots until it becomes zero.

There are two main approaches to vision-based homing using the panoramic information as seen from home. Image-based homing (e.g. [5]) attempts to derive a homing-vector directly from discrepancies observed in the raw images captured from the differing views of home and current location. Whereas, landmark-based homing attempts to derive a homing-vector by firstly detecting salient features, such as landmarks, in the views and then deriving a solution from the discrepancies herein (e.g. [6]).

Our landmark-based approach to visual homing (i) is very simple, intuitive and computationally cheap, (ii) requires only a parsimonious representation of the environment, (iii) provides a large catchment area, (iv) requires only simple, approximate landmark correspondence, (v) has an inherent tendency to avoid collisions with landmarks.

3. Robot Setup

The mobile robot used in our real-world experiments (fig. 1) is a custom built robot, designed for our visual-based insect behaviour experiments. However, it was not designed with visual homing in mind [7]. A full $360°$ view, a panoramic sensor, is what is ideally required for vision-based homing [5, 6]. To achieve a panoramic view for our system we have had to employ a behaviour-based (i.e. spinning) solution. Despite the practical restrictions however the resulting behaviour has been quite successful.

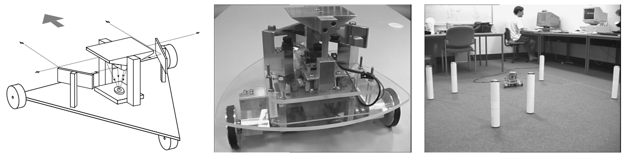


Figure 1. Robot and Test Environment

4. Homing Algorithm

Landmarks in the panoramic image are simply identified as contiguous regions of significantly light or dark luminance. The bearings of these landmarks (i.e. centre of gravity) and their angular size are then noted. A snapshot is thus only represented by a list of bearings (θ_i) and angular sizes (α_i) and is given as:

$S = [(\theta_1, \alpha_1), (\theta_2, \alpha_2), ..., (\theta_n, \alpha_n)]$ where $\theta_i \dot{<} \theta_{i+1}$.

4.1. Landmark Correspondence

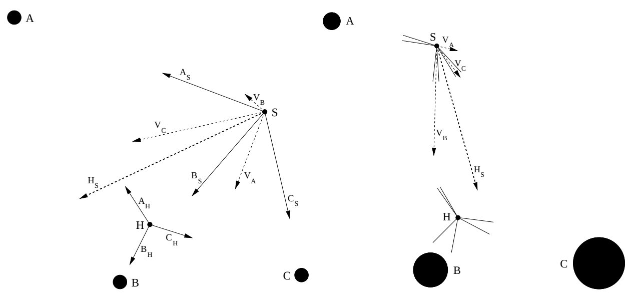
The first task is to match up corresponding landmarks (bearings) from each snapshot as best as possible. Each landmark in one snapshot is paired with exactly one landmark from the other snapshot. (This is straight forward due to the fact that we consider all landmarks to be homogeneous.) To achieve an optimum pairing of landmarks, and hopefully a correct one, we search for the matching that gives the least mean square error of the pairing error. Essentially, we strive to minimise $\sum_{i=1}^{n} |\theta_i \dot{-} \beta_i|^2$ where θ_i and β_i represent the bearings of paired landmarks. Although this is not guaranteed to provide a 100% correct correspondence between landmarks, it is sufficient. An approximation is all that is required for successful homing.

To avoid the possibly excessive computational requirements of exhaustively searching for the optimum pairing (O($n!$)) we employ several alternative techniques which provide a close approximation at much reduced expense. Using a correlation approach, for example, the complexity can be reduced to O(max($n^2, n\binom{m}{n}$)), where n and m are the numbers of landmarks in each snapshot. Or when this is too expensive a stable marriage implementation can be used (O(nm^2)). Experiments have shown that the homing algorithm is very tolerant of less than optimal and blatantly wrong matchings. This is due to the fact that, in general, the further away from home, the greater the discrepancy between snapshots and the greater the chances of incorrect pairing, the less need for correct matching.

4.2. Computing The Homing Direction

We have chosen a very intuitive method of computing the homing direction given only a list of paired landmarks (bearings and apparent sizes).

First consider the case of using only bearing information. Essentially what is required is to move the robot in a direction which brings the bearings of landmarks seen at the current position closer to the bearings of the landmarks seen from home. Given only bearing information, the obvious answer is to move perpendicularly to the current bearing of a landmark, in the appropriate direction to bring it closer to the correct bearing as seen from home. For each pairing of bearings, there is a correctional vector. By summing over all the correctional vectors (V_i) we arrive at our homing direction H_s (fig. 2(a)). However, we also weight these correctional vectors by the error (difference in bearing) between the bearing pairs. In this way the homing algorithm will strive to correct the worst pairings faster than the best.



(a) Bearing Cues (b) Apparent-Size Cues

Figure 2. Computing the Homing Direction

Although bearing information alone is usually enough for homing, we also include apparent size information to improve the homing behaviour. This simply involves adding further correctional vectors correcting for the apparent size of landmarks. This is implemented in exactly the same way as before except the correctional vectors will be directed towards or away from the landmarks in order to improve their angular size (fig. 2(b)). Again, the correctional vectors are weighted, but in this case by the differences in angular size between landmark pairs.

Our final and improved homing vector is thus computed by adding the homing vector computed for apparent size cues to our original homing vector for bearing cues.

5. Results

Figure 3 shows the simulated homing behaviour for four test arenas. In each case the robot is homing in on the centre of the arena. Figure 3(a) shows how the homing behaviour performs in a simple arena. It is worth noting that this arena would cause problems if one were only using bearing information. In these situations, where the landmarks and the target location lie along a line, ambiguity would arise if apparent-size cues were not utilised. Figures 3(b,c) not only show the landmark avoidance behaviour but also show the effect visual occlusion can have on the otherwise smooth homing path. Finally, figure 3(d) shows how the homing performs in a more cluttered environment. Apparent size cues greatly assist in avoiding looming landmarks. Despite occlusion problems, the robot was able to home successfully in each case.

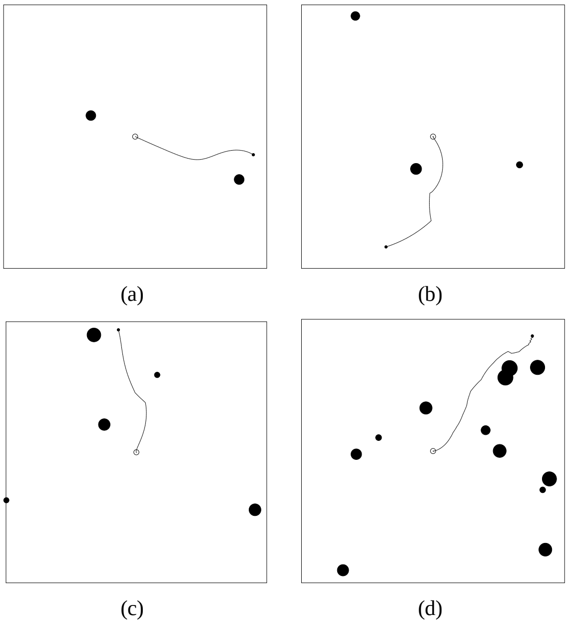


Figure 3. Homing Behaviour (simulation)

Figure 4 shows an example of the robot homing behaviour observed in our real-world experiments. The discrete nature of the homing path is a consequence of the way the robot must capture its panoramic images. The mobile robot homes successfully by incrementally improving its position, in discrete steps, until a close match between the current snapshot and memorised home snapshot is attained.

6. Conclusions

We have presented a simple extension to our original homing algorithm (see [8]) which significantly improves its performance. The addition of landmark apparent size cues

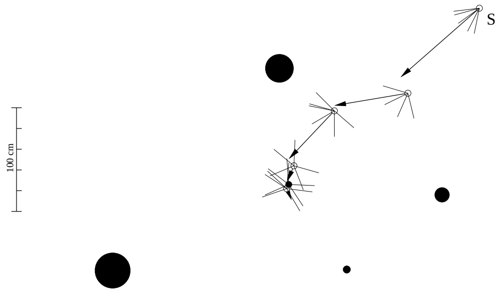


Figure 4. Homing Behaviour (real-world)

assists homing by providing a more robust homing vector. This is particularly evident in certain landmark configurations. Apparent size cues, however, also provide a simple and effective method of reinforcing landmark avoidance.

The main advantage of landmark-based homing over image-based homing is the extent of the potential catchment area. With landmark-based homing there is essentially no position in which the discrepancy between current and home views is so bad as to render homing unworkable. This is however, not the case with image-based homing.

If simple, not necessarily heterogeneous, landmarks can be detected within the environment and an external frame of reference is available, then landmark-based homing can provide a very robust method of real-time navigation.

References

[1] U. Brünnert, A. Kelber, and J. Zeil. Ground–nesting bees determine the location of their nest relative to a landmark by other than angular size cues. *Journal of Comparative Physiology*, 175:363–369, 1994.

[2] B. A. Cartwright and T. S. Collett. Landmark learning in bees. *Journal of Comparative Physiology A*, 151:521–543, 1983.

[3] B. A. Cartwright and T. S. Collett. Landmark maps for honeybees. *Biological Cybernetics*, 57:85–93, 1987.

[4] T. S. Collett. Landmark learning and guidance in insects. *Philosophical Transactions of the Royal Society of London B*, 337:295–303, 1992.

[5] M. O. Franz, B. Schölkopf, and H. H. Bülthoff. Homing by parameterized scene matching. Technical Report 46, Max-Planck-Institut für biologische Kybernetik, Tübingen, Germany, Feb. 1997.

[6] J. Hong, X. Tan, B. Pinette, R. Weiss, and E. M. Riseman. Image-based homing. In *Proceedings of the 1991 IEEE International Conference on Robotics and Automation*, pages 620–625, Apr. 1991.

[7] K. Weber, S. Venkatesh, and M. V. Srinivasan. Insect inspired behaviours for the autonomous control of mobile robots. In *From Living Eyes to Seeing Machines*, chapter 11, pages 226–248. Oxford University Press, 1997.

[8] K. Weber, S. Venkatesh, and M. V. Srinivasan. Insect-inspired robotic homing. *Adaptive Behavior*, 1998. (To appear).

[9] R. Wehner. Arthropods. In F. Papi, editor, *Animal Homing*, volume 2, pages 43–144. Chapman and Hall, 1992.