Landmark Vector Model with Quantized Distance for Homing Navigation

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Abstract

Inspired by astonishing navigation ability of insects and other animals, many studies observed their behaviors, and considered biomimetic application to robotic systems by investigating mechanisms based on various senses. In this paper, we suggest a new landmark vector model for homing navigation with quantized distance information. The method is highly successful for homing navigation in both perspectives of angular error and success rate. This work has been published in Yu and Kim (2011).

Introduction

Animals have developed navigation skills based on various senses. Desert ants and honeybees are known to use visual information (Collett, 1996), turtles migrating long distance rely on magnetic compass (Luschi et al., 1996), while other studies have shown that birds use olfactory cues to navigate (Papi, 1990). Many studies have focused on designing bio-inspired navigation algorithms for robotic systems inspired by the excellent performance animals demonstrate. Among them, vision-based homing navigation has been studied through a number of bio-inspired algorithms. One of the simplest method suggested, inspired by desert ants and honeybees, is the 'snapshot model' (Cartwright and Collett, 1983).

In the snapshot model, currently obtained visual information is compared to that in the snapshot image taken at home location. Several different methods were suggested to process the snapshot images for homing navigation. One of the methods based on the concept is the average landmark vector (ALV) model by Lambrinos et al. (2000).

The ALV model is one parameter method where the average landmark vector is obtained by averaging every unit-length landmark vectors perceived in the snapshot. Comparing the average landmark vectors obtained from snapshots taken at the current location and at home location, it is sufficient to guide the agent for the homing direction. The ALV model is based on a simple representation of the environment with powerful performance results in homing navigation, but the model necessarily requires a reference compass information.

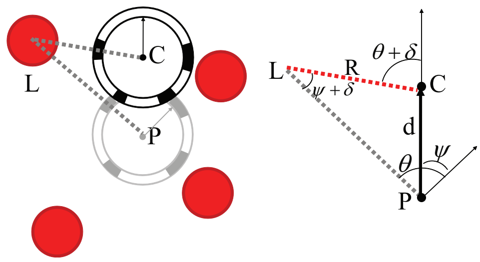

Figure 1: Image shift of landmarks when the agent moves from the position P to C with moving distance d. The head orientation angle changes by ψ, and the viewing angle of a landmark is θ and $\theta + \delta$ in two positions, respectively (modified from Yu and Kim (2010)).

In this paper, we propose a new landmark-based navigation algorithm without any reference compass. The method we suggest is the distance-estimated landmark vector model (DELV) using quantized distance estimation along with the rotational landmark arrangement matching. This work has been published in Yu and Kim (2011).

Methods

While the ALV model (Lambrinos et al., 2000) considers landmark vectors in unit length, and perceives only angular directions of landmarks ignoring their distances, the DELV model includes distance information as well as the angular position of landmarks in the landmark vector. Both methods share similar concept in perceiving landmark information as a vector form, but the matching process between information in two snapshots have a different point of view in exploiting the landmark vectors.

Distance estimation and quantization

The DELV method includes distance information of landmarks in the landmark vector representation, which can be obtained by inducing the image motion. Using an omnidirectional camera, the mobile robot is able to monitor 360° view of its surroundings, and the angular position of landmarks observed in the view is shifted as the robot moves one step forward. Fig. 1 describes the geometric relationship between angular shift and the distance, and Eq. 1 shows the distance estimation based on the relationship.

$$R = \frac{dsin(\theta - \psi)}{sin(\delta + \psi)} \quad (1)$$

As in Eq. 1, the estimation of landmark distance is affected by variables such as θ, δ and d, and their accuracies can affect the estimation results. The angular position of landmarks θ and $\theta + \delta$ is sensitive to noise in the captured image, while the moving distance d is influenced by odometry error. In addition, it may be plausible to argue that insects or other animals perceive the distances to landmarks in a relative manner rather than in the absolute values. Therefore, we apply quantization on the estimated distance to landmark vectors. Through arrangement matching of landmark vectors for heading direction estimation and homing direction computation, it is shown that the landmark vector model with quantized distance is effective, which will be described in more details.

Rotational matching of landmark vectors

The landmark vector set perceived at home location is stored as a reference map in which the landmark vectors at an arbitrary location will be projected to obtain a homing direction. By reversely projecting the landmark vector obtained at the current location to the reference map, the end point of each landmark vector would represent the vector from the home location to the current location. With N landmarks available in the environment, the estimation on the current position $p^k(x)$ is defined as the average of the landmark vectors projected on the reference map. Assuming the appropriate arrangement k, the equation is given as:

$$p^k(\mathrm{x}) = \frac{1}{N} \sum_{i=1}^{N} \left[V_i^R(\mathrm{x}_o, \alpha_r) - V_i^k(\mathrm{x}, \alpha) \right] \quad (2)$$

where $V_i^R(\mathrm{x}_o, \alpha_r)$ is the landmark vector for the i-th landmark in the reference map, and $V_i^k(\mathrm{x}, \alpha)$ is the i-th landmark vector with the matching order k at the current location x.

Without a reference compass, the DELV method solves the correspondence problem between landmarks in a pair of snapshots with the rotational arrangement matching of landmark vectors. The variance of end points of the projected landmark vectors is used as the criterion for finding the best matching order z and heading direction α_z as:

$$\arg\min_{k,\alpha} \quad \left[\sum_{i=1}^{N} \left(\left[V_i^R(\mathrm{x}_o, \alpha_r) - V_i^k(\mathrm{x}, \alpha) - p^k(\mathrm{x}) \right] \left[V_i^R(\mathrm{x}_o, \alpha_r) - V_i^k(\mathrm{x}, \alpha) - p^k(\mathrm{x}) \right]^T \right) \right] \quad (3)$$

Results and discussion

Vector map results in Fig. 2 (a) to (c) indicate the decided homing direction with the suggested method for three different quantization levels. Angular error curves in Fig. 2 (d) efficiently compares

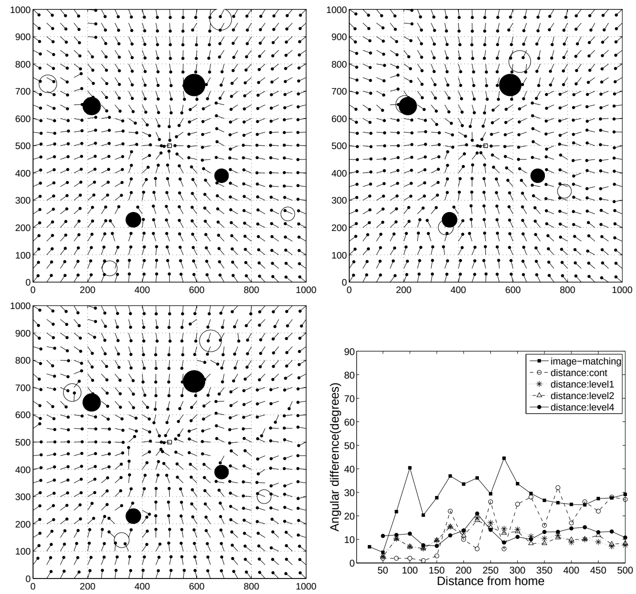

Figure 2: Vector map results with quantization in (a) level 1, (b) level 3, and (c) level 5, respectively and (d) error curves

the results and show low angular errors. As a result, the DELV model with quantized distance shows homing ability with simple representation of environments and low complexity in computation even without any reference compass information. The quantization of distances to landmarks may allow some errors in heading direction search and current location estimation, but experimental results showed that the method leads to the homing direction decision.

Acknowledgements

This work was supported by the Mid-career Researcher Program through an NRF grant funded by the MEST in South Korea (No. 2011-0000210).

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