Investigation of Navigating Mobile Agents in Simulation Environments

Theses of the Doctoral Dissertation

Richárd Szabó

Department of Software Technology and Methodology
Faculty of Informatics
Loránd Eötvös University

Updated version based on the opinion of the opponents

Ph.D. School of Informatics
Ph.D. Program in Informatics
Program Director: Prof. Demetrovics János

Supervisor:
Prof. George Kampis
Department of History and Philosophy of Science

Budapest, 2006. 2008.

Introduction

Human tries to ensure comfort for himself from the beginning of times. Scientific and technological advance, serving this need, produced the ’physical body’ and the ’power’ during the industrial revolution, while information revolution is at the doorstep of creating the ’spirit’, which controls the body autonomously. One of the key tasks of this controlling intelligence is navigation. Navigation may clarify location and relation of objects and living beings, and it aids the recognition of the environment surrounding the acting agent. These are important elements of further tasks solving.

There are two alternative ways to realize efficient navigation. An obvious possibility is the constructive, engineering approach that creates appropriate representations and algorithms from scratch after a deep investigation of the problem. Another attitude reaches its goal through the analysis of successful existing methods. Animals may supply these functioning navigational solutions.

Researchers must be prepared for several difficulties of navigation. Actors placed in real-world environments — in contrast to classical artificial intelligence — do not use preprocessed, abstract senses for decisioning. They rely only on finite-range, noisy, error-prone perceptions and construct the representation of the environment based on low-level signals of sensors. At the same time actions of the agents are inaccurate and faulty. Furthermore, robots have to determine their position related to the perceived environment and the location of neighboring objects related to their stance for navigating appropriately. During navigation environment map has to be formed using the incoming sensor information. This means that former inaccurate measurements are ameliorated, confidence of precise perceptions is raised, new information appears at fresher parts of the map, and former false measurements are removed. An important question is the choice of appropriate representation of the map. The solution has to adapt to several properties of the problem: the specificities of the task at hand, the capability and the modality of sensors, the surroundings of the job, and the computational capacity. After map creation agents must perform motion planning and control to find their way to the goal taking into consideration the character of the terrain and their kinematic motion constraints.

A further difficulty of navigation is the dynamic nature of environments. This property has to be mirrored on the map, in accordance with the type of the variation. Another active research area is the field of outdoor navigation because off-the-self solutions are efficient only in man-made, artificial environments and far less useful in diversified outdoor terrains where easily recognizable landmarks are sparse and new forms of motion planning and control are necessary.

A navigating robot has to provide a universal, autonomous, robust, and real-time solution of all the problems outlined above. This is one of the most important open questions of mobile robotics.

Agent-based simulation is a unique tool for performing navigation-related experiments. Simulation allows the preliminary investigation of the problem and the creation of hypotheses. Having a different viewpoint of the task deeper understanding is possible. Simulation experiments are performed in a virtual world saving development and execution time, cost, and energy. Furthermore this solution is much more flexible since the complexity and the reality of the tests can be tuned according to the needs. Other advantages are that researchers may focus on the important elements of the problem ignoring uninteresting details and they can exploit resources more economically. Additionally the robustness of the employed algorithms can be checked in the simulator. After eliminating design-time errors caused by differences between the model and the reality, invented algorithms may work in real-world, natural environments.

In the dissertation I investigate the navigation of artificial and natural agents, namely robots and 'ants'. First of all, I overview issues raised by the usage of simulation as a scientific method. Then I focus on the domain of navigation presenting renowned engineering and natural solutions. After that I present my results and experiments in a robotic simulation contest as a first step for further investigation of navigation. I analyze occupancy grid-based environment representation of robots in the following three chapters. First I show a functioning discrete representation what makes possible the exploration and mapping of various environments. Later I extend this solution with a topological process and then with a vision sensor. I investigate food gathering ants in the last chapter and the relationship between order of the environment and performance of the ant colony.

My works are referred by Citeseer Scientific Literature Digital Library and DBLP Computer Science Bibliography.

Used tools

I applied the simulation of intelligent agents for the investigation of navigation problems. Although simulation cannot substitute classical scientific methodology it is a valuable complementary tool when analytical solution of problems requires extreme effort.

Simulators are also useful in cases of the examined map-building and exploration tasks. I implemented models of physical-world problems in the Webots mobile robot simulator and Repast general-purpose agent simulator, using C and Java programming languages. Hypotheses created during preliminary investigations were tested running lots of simulations varying parameters of the models. Theses are based on the results of these tests.

Results

This dissertation presents contributions to the navigation of simulated agents in three main areas.

In the course of the robot simulation contest I dealt with the creation of reactive intelligent behavior with no environment representation.

Further researches performed in the Webots simulator compare the functioning of various map building and path planning methods. Although theses related to map building are based on known algorithms, their integration and usage in simulator are unique and may form the basis of new developments.

Third part of the dissertation contributes to biological based navigation. In this work I investigate the efficiency of 'food gathering ants' and the evolution of the collecting process depending on the configuration of the environment. Group communication has a crucial role in the described type of navigation.

Thesis 1 *I developed a reactive, modular robot model without explicit environment representation working in the Webots simulator. The controller was the runner-up of the 1999 and the winner of the 2000 Artificial Life Creators Contest international robot competition.*

During the contest the goal of the competitors was to navigate in the complex environments containing some obstacles and to find randomly placed chargers before their batteries run flat. Robots were controlled for limited time periods hence reactivity was a critical issue. For this reason I implemented a task decomposition by activity without complete environment representation ([1]), similar to Brooks' behavior-based architecture. The result of the competition for the control among the modules was determined by perceptions, motivations, and former actions. Simplified image processing helped in finding energy sources. Motion was controlled by Braitenberg-type modules responsible for obstacle avoidance, charger approach, and recharging. The direct consequence of the competition was the winning of the simulator program as a first prize. However, the contest also gave motivation for further investigation of navigation.

Thesis 2 *I was the first to implement an occupancy grid based map building algorithm using value iteration as path planning in the Webots simulator. The robot employs ultrasonic range sensors to produce the map of the modeled environment and then successfully explores various test terrains.*

The selected task is a common problem in ethology and in robotics as well. Complete exploration of the neighborhood is crucial for the survival of animals and it is inevitable for the efficient solution of planned everyday robotic tasks, like cleaning, gathering, surveying. Following Thrun's work as a first step I created an inverse sonar sensor model of a modified Khepera robot and I determined obstacle distances in the neighborhood. Measurements gathered in a local occupancy grid were merged into the global map using position information of a supervisor program. This process also meant the temporal integration of senses to minimize the role of noise in perceptions while creating an increasingly more confident map. After map building a version of value iteration determined the distance of the closest unexplored region from every position. The local minimum of the created cost matrix and obstacle avoidance together helped the controller aiming at new directions ([2], [3]). The developed robot explored five different environments successfully, including open area, maze, and former contest terrains, and calculated their occupancy probability maps.

Thesis 3 *I appended a topological graph based path planning algorithm to the occupancy grid map replacing value iteration. I demonstrated that the new solution enables more efficient environment exploration.*

Since value iteration is a memory consuming algorithm and uses only local information for navigation, it seemed a promising improvement to replace with a topological graph-based solution ([4], [5]). For this reason, as a first step of the occupancy grid vectorization I implemented a thinning algorithm. Then I chained the result to graph edges using a modified version of Tombre et al.'s method. Finally I optimized the graph with Rosin and West's segmentation procedure and with a pruning algorithm to get a directly explorable graph representation of the environment. The new navigation method alternated between an A^*-based path planning and the former obstacle avoidance behavior. The necessary time to solve the task dropped to 65–80% related to the value iteration method. The reason behind the improvement was that the graph governed the robot to far-away unexplored regions more efficiently, and following the edges the robot could move on the middle lines of corridors without the need to avoid walls.

Thesis 4 *I extended the occupancy grid map building with the utilization of camera images. This approach integrates former obstacle avoidance using ultrasonic range finder with an appearance-based method. Map building with both sensor types in the context of topological graph path planning generally results faster exploration.*

For the accurate knowledge of the neighborhood and the creation of appropriate environment mapping it is advisable to utilize several sensors and different sensing modalities. Accordingly, I introduced the usage of camera what enabled more efficient and robust exploration in cooperation with sonars ([6]). The new tilted head-camera determined the extent of the floor in moving directions from bottom to up, and the results were mapped to obstacle distances by a previously created experimental function. This information was integrated into the global occupancy grid map. Periodic turning around and photo taking extended the former path planning procedure. Utilization of camera with topological graph was mainly advantageous in the case of wide open spaces when photos cover large areas. The exploration time decreased to 70–80% in such environments. There was no significant advance in terrains including narrow corridors and small rooms. Utilization of camera with value iteration did not improve exploration remarkably because path planning were founded only on information appearing in the local environment what was not necessarily optimal.

Thesis 5 *I explored the relationship between the initial disorder in the environment and the performance of the ant foraging behavior in the model of Deneubourg et al. and I found that the performance of the anthill monotonically decreases as the initial disorder of food increases. I further studied how the configuration of the task governs the level of coordination in the behavior of the ant colony and I demonstrated that during the development of the process the minimal disorder of the ants occurs about the same time when the food disorder peaks. Finally, I presented that growing initial distribution of the food amplifies the stochastic nature of the algorithm expressed in the random behavior of the ants.*

This thesis is the result of a cooperative work with László Gulyás and László Laufer ([7], [8], [9]). During the research I implemented Deneubourg et al.'s model in the Repast simulator and I created the framework for our investigation. We analyzed the findings and drew the conclusions together.

We were interested in how social insects solve the gathering problem efficiently and almost optimally what is a hard task of collaborative robotics. We also tried to answer what was the role of the environment in the motivation of the workers and in the regulation of the working process.

For this analysis we employed average distance between pairs of food units as disorder of the food configuration and we found that the execution time depended monotonically on this measure. We also demonstrated that this dependence was not trivial, by comparing our findings to the performance of uncoordinated, random walking ants.

We studied the time-trajectory of food disorder together with the level of coordination in the ant colony in the case of single food source. We used the same disorder measure for ants as for the food. We observed that the disorder of the ant colony jumped up in the phase of exploration for food, gradually diminished after the finding of the source, and finally raised again after the collection of food. At the same time disorder of the food increased during the gathering process until more food units were collected in the hive than were left in the source and then the disorder started to diminish. Our main finding was that the ant colony reached its minimum disorder about the same time when the food disorder peaked. This was when the ants established the 'optimized' trail between the source and the nest.

We also found that, in case of a single food source, increasing the disorder of the initial food configuration resulted in higher variance across the runs. While the food disorder curve stayed fairly similar, the disorder of the ant colony differed more with increasing variation in the initial food placement, especially in the final phase of the process. The behavior of the ant colony became more dependent on random factors. This dependence was on probabilistic elements of the foraging algorithm, and not in the random initial placement of the food units, even though the distribution of food controlled the latter.

Publications on the topic of the dissertation

[1] R. Szabó. *Mobil robotok szimulációja*. Eötvös Kiadó, 2001.

[2] R. Szabó. Navigation of simulated mobile robots in the Webots environment. *Periodica Polytechnica — Electrical Engineering*, 47(I-II):149–163, 2003.

[3] R. Szabó. A foglaltsági háló és már térképépítési stratégiák. In E. Kubinyi and Á. Miklósi, editors, *Megismerésünk korlátai*, pages 135–145. Gondolat Kiadó, 2006.

[4] R. Szabó. Topological navigation of simulated robots using occupancy grid. *International Journal of Advanced Robotic Systems*, 1(3):201–206, 2004.

[5] R. Szabó. Combining metric and topological navigation of simulated robots. *Acta Cybernetica*, 17(2):401–417, 2005.

[6] R. Szabó. Occupancy grid based robot navigation with sonar and camera. In *Proceedings of CSCS'2006, The Fifth International Conference of PhD Students in Computer Science,University of Szeged*, 2006.

[7] L. Gulyás, L. Laufer, and R. Szabó. An information theoretic approach to stigmergy: The case of foraging ants. In *Proceedings of AISB'06: Adaptation in Artificial and Biological Systems*, volume 3, page 203, 2006.

[8] L. Gulyás, L. Laufer, and R. Szabó. Measuring stimergy: The case of foraging ants. In *Proceedings of the Fourth International Workshop on Engineering Self-Organizing Applications (ESOA 2006/AAMAS 2006, May 2006, Hakodate, Japan*, pages 76–91, 2006.

[9] L. Gulyás, L. Laufer, and R. Szabó. Measuring stimergy: The case of foraging ants. In S. Brueckner, S. Hassas, M. Jelasity, and D. Yamins, editors, *The Fourth International Workshop on Engineering Self-Organizing Applications (ESOA 2006)*, number 4335 in Lecture Notes in Artificial Intelligence, pages 50–65. Berlin, 2007.

[10] R. Szabó. Neural network controlling architectures in autonomous agents. In *Agents Everywhere – Proceedings of the First Hungarian National Conference on Agent Based Computing*, pages 99–109, 1999.