2012 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 7-12, 2012. Vilamoura, Algarve, Portugal

"Can ants inspire robots?" Self-organized decision making in robotic swarms

Arne Brutschy*, Alexander Scheidler†, Eliseo Ferrante*, Marco Dorigo*, and Mauro Birattari*
*IRIDIA, CoDE, Université Libre de Bruxelles, Brussels, Belgium
Email: {arne.brutschy, eferrante, mbiro, mdorigo}@ulb.ac.be
*Fraunhofer Institute for Wind Energy and Energy System Technology, Kassel, Germany
Email: alexander.scheidler@iwes.fraunhofer.de

In swarm robotics, large groups of relatively simple robots cooperate so that they can perform tasks that go beyond their individual capabilities [1], [2]. The interactions among the robots are based on simple behavioral rules that exploit only local information. The robots in a swarm have neither global knowledge, nor a central controller. Therefore, decisions in the swarm have to be taken in a distributed manner based on local interactions. Because of these limitations, the design of collective decision-making methods in swarm robotic systems is a challenging problem. Moreover, the collective decision-making method must be efficient, robust with respect to robot failures, and scale well with the size of the swarm.

In the accompanying video, we introduce a collective decision-making method for swarms of robots that is based on positive feedback. The method enables a swarm of robots to choose the fastest action from a set of possible actions. The method is based solely on the local observation of the opinions of other robots. Therefore, the method can be applied in swarms of very simple robots that lack sophisticated communication capabilities.

The task at hand is a foraging task, in which the robots have to harvest an object from a source and bring them to their nest (see Fig. 1 for an explanation of the experimental setup). The robots have the choice of taking one of two paths, with each path representing a possible action to take, that is, there are two actions, called A and B. In this study, it is assumed that action A is always the fastest action.

Path and shortest path finding have been studied intensively in swarm robotics. Most of the proposed methods are based on the simulation of pheromones. Several approaches have been tested, for example, based on heat [3], alcohol [4], or phosphorescent glowing paint [5].

In the proposed method, every robot has its own *opinion* about which is the *fastest action* (i.e., shortest path). Each robot executes what the action that is, in his opinion, the fastest. Between executions, robots can observe the opinions of other robots. They store these opinions in their memory, which retains up to k observations. Upon making a new observation, the oldest one in memory is replaced. Observations do not decay over time. Robots can decide to change their own opinion based on these observations and the so-called k-*Unanimity rule*, defined as follows:

A robot switches to opinion X if and only if all k observations stored in its memory are of opinion X.

The k-Unanimity rule leads to consensus on a single opinion, and therefore action, because it induces positive feedback on the opinion that is in the majority. Moreover, due to a bias induced by the different execution times, with high probability the consensus is on the opinion representing the fastest action. For example, if opinion B is held by most robots, then it is more likely that another robot switches from A to B than that a robot switches from B to A. Consequently, with high probability, the swarm moves towards consensus on opinion B. The decision making method that we present in this work has several advantages over the common *Majority rule* [6]. In particular, in our method, no teams have to be formed and the accuracy of the decision can be adjusted.

We conducted a total of three real robot experiments, each with 15 trial runs. Additionally we conducted simulation experiments using the ARGoS simulation framework, using 2D-space and kinematic physics engine [7]. For each simulation experiment, we conducted 50 000 trial runs. In Experiment I, the ratio between the execution times of the two actions actions A and B is ≈ 1.3, and the robots have a memory of $k = 2$. This experiment resulted in 10 out of 15 runs that converged successfully on the shortest action A with runs that took 15 min on average. In Experiment II, increasing the execution time for action B such that the ratio between the execution times of the actions A and B_{long} is ≈ 1.9 led to 13 successful runs, but also doubles the time needed to converge. In Experiment III, increasing the memory of the robots to $k = 4$ resulted in 12 runs that converged to action A and in a strongly increased convergence time. The video shows a run of Experiment I. See Fig. 2 for a summary of the results for all experiments.

ACKNOWLEDGEMENTS

This work was partially supported by the European Research Council via the ERC Advance Grant "E-SWARM: Engineering Swarm Intelligence Systems" (grant 246939). The information provided is the sole responsibility of the authors and does not reflect the European Commission's opinion. The European Commission is not responsible for any use that might be made of data appearing in this publication. Alexander Scheidler is supported by the "Postdoc Programme" of the German Academic Exchange Service (DAAD). Arne Brutschy, Marco Dorigo, and Mauro Birattari acknowledge support from the F.R.S.-FNRS of Belgium's French Community. Eliseo Ferrante and Alexander Scheidler acknowledge support from the Meta-X project, funded by the Scientific Research Directorate of the French Community of Belgium.

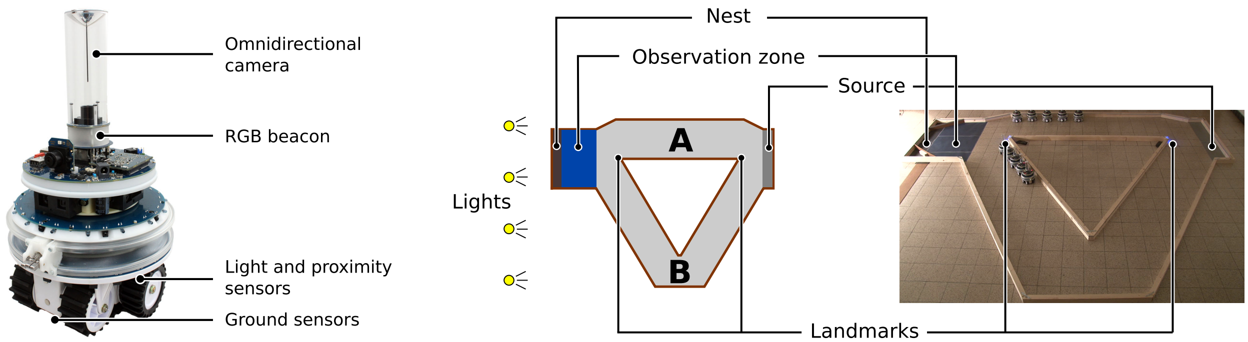

Fig. 1. Experimental setup. Left: The robots employed in the experiments are called *foot-bots*. Foot-bots use the RGB beacon to show their opinion to others. They use their omni-directional camera to navigate and to observe the opinions of other robots in close proximity. Middle: A schematic representation of the arena used in the experiments. Right: A photo of the real installation. The area has a size of 4.5 m×3.5 m. The robots travel constantly between the nest and the source by navigating with respect to the lights (anti-phototaxis and phototaxis, respectively). No map of the environment is available. Depending on their individual opinion, robots choose one of the two paths between the nest and the source by using the landmarks as a cue for navigation. In the observation zone, robots observe each other's opinions.

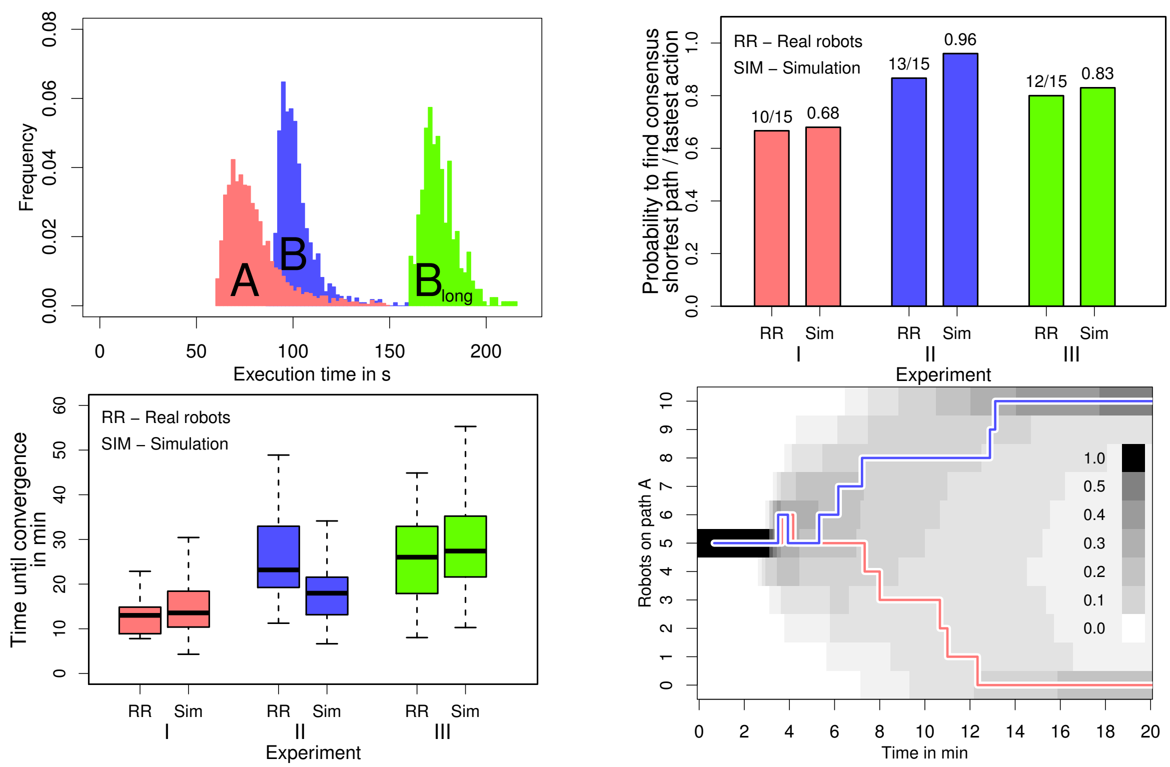

Fig. 2. Summary of the experiments and their results. Top left: Distributions of the travel times for path A, path B, and path B_{long} in experiment II, recorded in the real robot experiments (15 trial runs each) and used for the simulation. Top right: Probability to find consensus on the shortest path for the real robot and simulation experiments. Bottom left: Time to converge on a single opinion for the real robot and simulation experiments. Bottom right: Distribution of robots over time collected over 50 000 trial runs in simulation of Experiment I. The shade of gray indicates the probability to find a certain number of robots with opinion A at a given time in the system. The two lines correspond to data collected in two real robot experiments.

REFERENCES

[1] M. Dorigo and E. Sahin, "Guest editorial. Special issue: Swarm robotics," *Autonomous Robots*, vol. 17, no. 2–3, pp. 111–113, 2004.

[2] E. Şahin, "Swarm robotics: From sources of inspiration to domains of application," in *LNCS 3342. Swarm Robotics. SAB 2004 International Workshop*, E. Şahin and W. M. Spears, Eds. Berlin, Germany: Springer, 2005, pp. 10–20.

[3] R. A. Russell, "Heat trails as short-lived navigational markers for mobile robots," in *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA 1997)*. Piscataway, NJ: IEEE Press, 1997, pp. 3534–3539.

[4] R. Fujisawa, S. Dobata, D. Kubota, H. Imamura, and F. Matsuno, "Dependency by concentration of pheromone trail for multiple robots," in *LNCS 5217. Proceedings of the International Conference on Ant Colony Optimization and Swarm Intelligence (ANTS 2008)*. Berlin, Germany: Springer, 2008, pp. 283–290.

[5] R. Mayet, J. Roberz, T. Schmickl, and K. Crailsheim, "Antbots: a feasible visual emulation of pheromone trails for swarm robots," in *Proceedings of the 7th international conference on Swarm intelligence*, ser. LNCS 6234. Berlin, Heidelberg: Springer-Verlag, 2010, pp. 84–94.

[6] M. A. Montes de Oca, E. Ferrante, A. Scheidler, M. Birattari, and M. Dorigo, "Opinion formation models with differential latency: A self-organized collective decision-making mechanism," *Swarm Intelligence*, vol. 5, no. 3-4, 2011.

[7] "ARGoS: a modular, multi-engine simulator for heterogeneous swarm robotics," 2012, http://iridia.ulb.ac.be/argos/.