Video: “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 (see [3] for an example). 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 object from a source and bring them to their nest (see Fig. 1 for an explanation of the robots employed and the experimental setup). The robots have the choice of taking one of two paths, with each path representing a possible action to take (i.e., there are two actions, called A and B). In this study, it is assumed that action A is always the fastest action.

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 fasted. Between executions, robots can observe the opinions of other robots. They store these opinions in their memory (up to k observations). 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. Fig. 2 illustrates this decision process.

We conducted a total of three real robot experiments, each with 15 runs. In Experiment I, the ratio between the execution times of the two actions 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 to ≈ 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. 3 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.

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] A. Gutiérrez, A. Campo, F. C. Santos, F. Monasterio-Huelin, and M. Dorigo, “Social odometry: Imitation based odometry in collective robotics,” *International Journal of Advanced Robotic Systems*, vol. 26, no. 2, pp. 129–136, 2009.

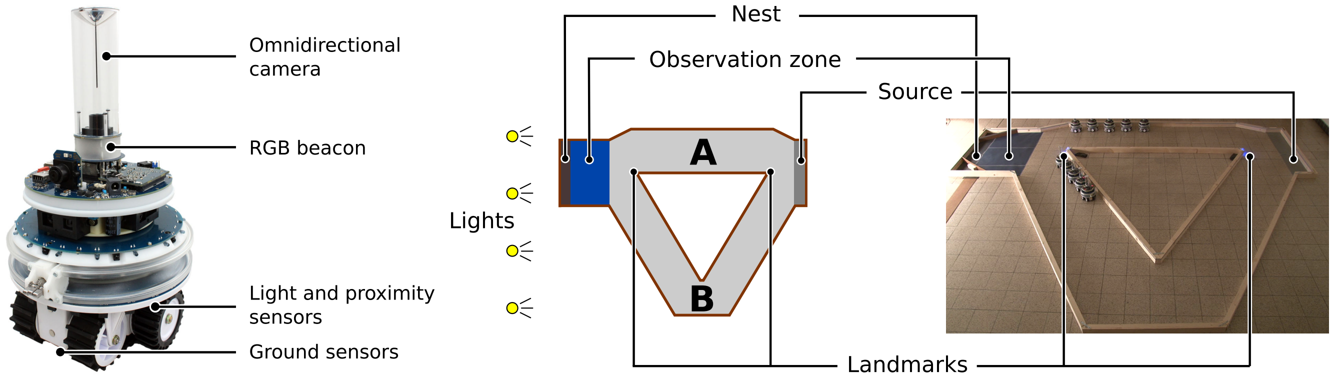

Fig. 1. Experimental setup. Left: The robots employed in the experiments are called *foot-bots*. Foot-bots use the RGB beacon to show their opinion to others. They use their omni-directional camera to navigate and to observe the opinions of other robots in close proximity. Middle: A schematic representation 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. Depending on their individual opinion, robots choose one of the two paths between the nest and the source. In the observation zone, robots observe each other's opinions.

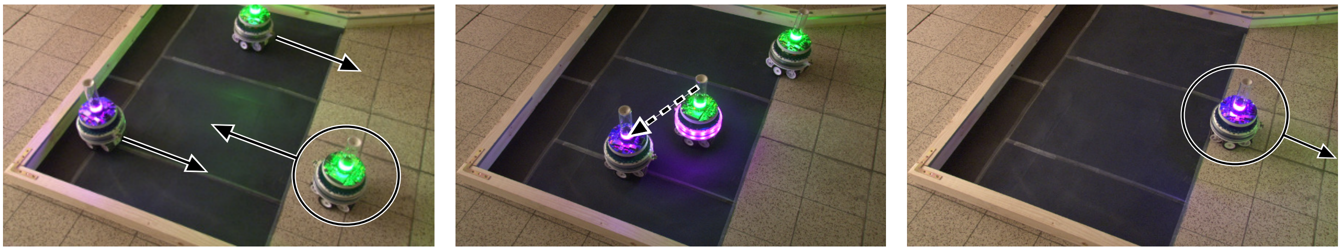

Fig. 2. Illustration of the observation and decision process shown on the example of a single robot. Left: A robot with opinion A (encircled) enters the observation zone. Middle: The robot observes another robot with opinion B (the robot shows this to the researcher by flashing its LED-ring) and stores the observation in its memory. Right: The robot leaves the observation zone and the application of the k-Unanimity rule changes its opinion to B.

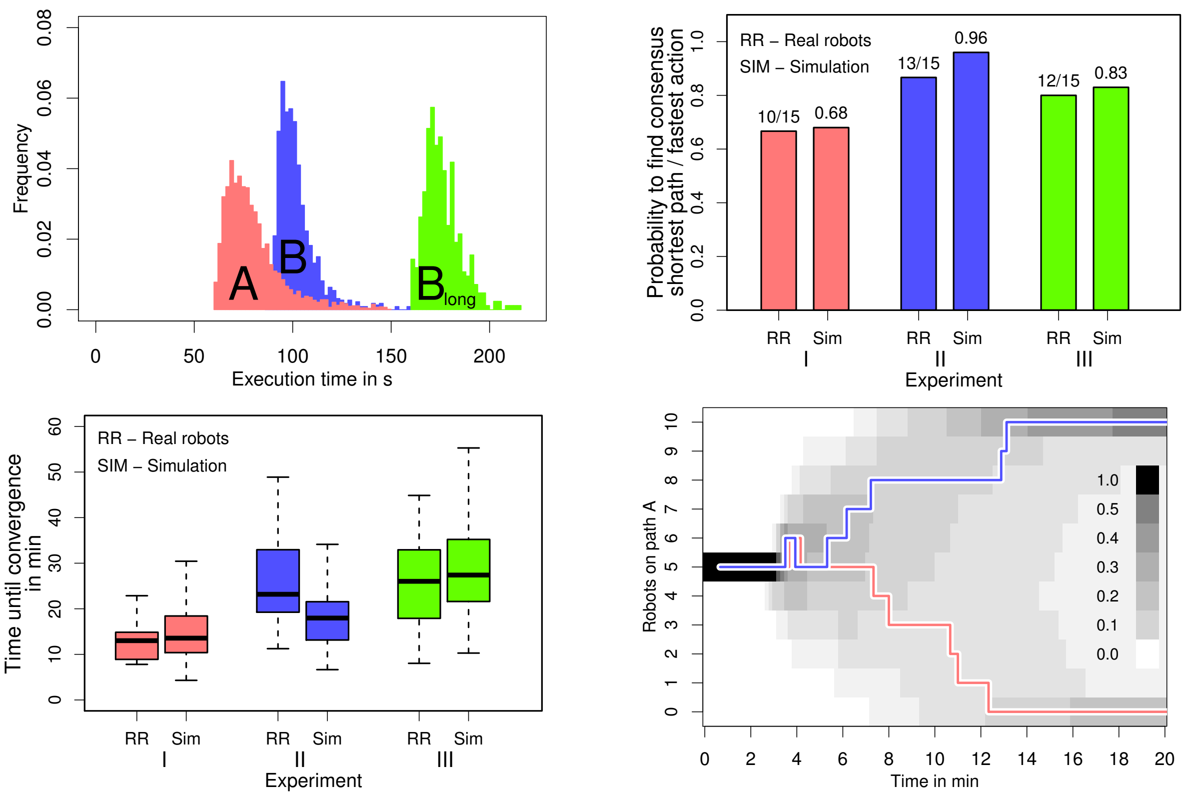

Fig. 3. Summary of the experiments and their results. Top left: Distributions of the travel times for path A, path B, and path B $_{\text{long}}$ in experiment II, recorded in the real robot experiments and used for the simulation. Top right: Probability to find consensus on the shortest path for the 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 simulations 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.