Enhancing cooperative transport using negotiation of goal direction

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Swarm robotics is a relatively new approach to the coordination of a system composed of a large number of autonomous robots. The coordination among the robots is achieved in a self-organised manner: the collective behaviour of the robots is the result of *local* interactions among robots, and between the robots and the environment. Each single robot typically has limited sensing, acting and computing abilities. The strength of swarm robotics lies in the properties of robustness, adaptivity and scalability of the group [5].

Foraging is a typical task considered in swarm robotics [4]. It can be decomposed in an exploration subtask followed by a transport subtask. The robotic metaphor consists in the search and retrieval of an object. Therefore, the nest is the metaphorical term for the goal and the prey is synonymous of the object to transport. Examples of applications of foraging are toxic waste cleanup, search and rescue, demining and collection of terrain samples.

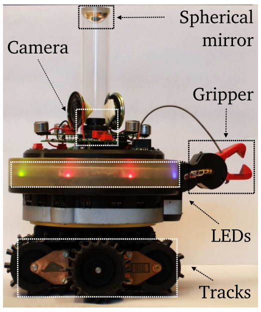
In our work, we address the case in which all robots completely lose sight of the nest during the exploration subtask of foraging. We assume that the robots have partial knowledge of the goal direction. For instance, they may have perceived the nest earlier and kept track of its approximate direction by means of odometry [2]. Using this approximate knowledge, if several robots attempt to transport a heavy prey in different directions they may fail to move the prey at all. Therefore, we introduce a mechanism to let the robots negotiate the goal direction. In order to meet the general principles of swarm robotics [5], this system is fully distributed and makes use of local communication only.

The mechanism we introduce is strongly inspired by a natural mechanism that has been long studied by biologists. We rely on a particular property of models designed to explain and reproduce the behaviour of fish schools and bird flocks [1, 7]. The models available in the literature are usually composed of three behaviours: an attraction behaviour that makes the individuals stick together, a repulsion behaviour that prevents collisions among individuals, and an orientiation behaviour that coordinates the individuals' motion. It is the last of these three behaviours that we transfer and implement in our robots. Informally, the orientation behaviour lets every individual advertise locally its own orientation and update it using the mean orientation of its neighbours. In the robotics experiment, the orientation advertised by the robots at the beginning is their initial estimate of the goal direction. A robot transmits orientation information using LEDs and perceives it thanks to an omnidirectional camera, as seen in Figure 1.

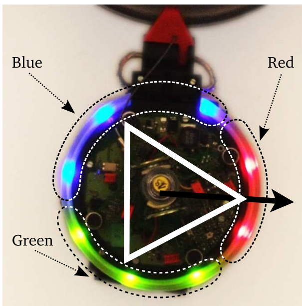
We conducted experiments with a group of four robots called *s-bots*, designed and implemented in the SWARM-BOTS project[1]. The robots have to transport a prey moving in a direction about which they have noisy knowledge. We assess quantitatively the performance of the negotiation mechanism implemented with respect to different levels of noise and different control strategies. Furthermore, we define three strategies involving negotiation at different stages of the experiments, and a strategy that does not make use of negotiation at all. These strategies are implemented and their performances are compared using a group of four robots, varying the goal direction and the level of noise in perception.

We identify a strategy in which robots negotiate and move at the same time that enables efficient coordination of motion of the robots. Moreover, this strategy lets the robots improve their knowledge

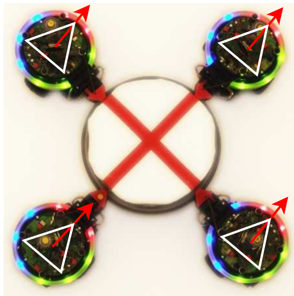
[1]For more details, see the project website: http://www.swarm-bots.org/



(a)



(b)



(c)

Figure 1: (a) The *s-bot*. (b) An *s-bot* displaying a direction using a triangular LED pattern. (c) Star-like formation of four *s-bots* around the prey as used in the experiment.

of the goal direction. Despite significant noise in the robots' communication, we achieve effective cooperative transport towards the goal and observe that the negotiation of direction entails interesting properties of robustness. The negotiation mechanism we have introduced is not only able to supply a group of robots with collective motion, but also to let each individual improve its own estimate of the goal direction by sharing knowledge with its neighbours. This mechanism may also be used to correct measures of odometry in multi-robot experiments, in a fully distributed fashion. This self-organised negotiation is likely to display properties of scalability besides the robustness shown in this paper. The mechanism makes use of visual communication and has several interesting properties. In particular, it is available when the prey is not in motion, and it is not distracted if the prey moves in irregular steps. Additionally, visual communication opens the door to collective motion with or without transport or physical connections. The topology of the communication network is also likely to be very flexible, allowing the robots to school in very diverse patterns.

We plan to integrate the cooperative transport in a more complex and challenging scenario of foraging, such as for instance the one used by Nouyan *et al.* [6]. This scenario would include an exploration phase preliminary to transport, in which robots lose sight of the nest before finding the prey. In this context, robots have a rough estimate of the direction of the nest by means of odometry. Improvement of this knowledge using negotiation negotiation is a critical feature of the scenario, necessary to let the robots transport the prey efficiently to the nest, even in presence of noisy communications and robot failure.

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References

[1] I. Aoki. A simulation study on the schooling mechanism in fish. *Bulletin of the Japanese Society of Scientific Fisheries*, 48(8):1081–1088, 1982.

[2] J. Borenstein and L. Feng. Measurement and correction of systematic odometry errors in mobile robots. *IEEE Trans. on Robotics and Automation*, 12(5):869–880, 1996.

[3] A. Campo, S. Nouyan, M. Birattari, R. Groß, and M. Dorigo. Negotiation of goal direction for cooperative transport. In *Lecture Notes in Computer Science : Ant Colony Optimization and Swarm Intelligence*, volume 4150, pages 191–202. Springer, Berlin / Heidelberg, 2006.

[4] Y. U. Cao, A. S. Fukunaga, and A. B. Kahng. Cooperative mobile robotics: Antecedents and directions. *Autonomous Robots*, 4(1):7–27, 1997.

[5] M. Dorigo and E. Şahin. Swarm robotics – special issue editorial. *Autonomous Robots*, 17(2–3):111–113, 2004.

[6] S. Nouyan, R. Groß, M. Bonani, F. Mondada, and M. Dorigo. Group transport along a robot chain in a self-organised robot colony. In *Proc. of the* 9^{th} *Int. Conf. on Intelligent Autonomous Systems*, pages 433–442. IOS Press, Amsterdam, The Netherlands, 2006.

[7] C. W. Reynolds. Flocks, herds, and schools: a distributed behavioral model. *Computer Graphics*, 21(4):25–34, 1987.