Extended Abstract of Ph.D Thesis
Communication in Swarms of Miniature Mobile Robots

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1. BACKGROUND

Swarm robotics is the study of large groups of relatively homogeneous robots and their task solving capabilities. The robots of a swarm robotic system are relatively simple and incapable when compared to the tasks that they are expected to accomplished [10]. Thus, it is important to have enough units and a distributed control law that is effective. Because the individual behaviour of social insects often inspires the control law design in swarm robotic systems, the control law of individual robots is usually referred to as individual behaviour. The behaviours of the robots are usually identical and make use of only local information. Combining these features, a swarm robot system offers potential advantages in robustness, flexibility and scalability [11]. However, the cause-effect of the individual behaviour in a swarm robot system is not straight forward when compared to the control law of a single robot. In other words, it is difficult to realize a specified system behaviour through designing the individual behaviours.

This thesis examines the problem of how to achieve coordination in a swarm of miniature mobile robots. We study mechanisms that enable robots to perform distinct roles in the course of their interactions. In particular, we investigate how simple forms of communication can lead to an effective allocation of roles. The first part of the thesis is concerned with the task of spatial segregation. The swarms are required to organise into centre-periphery patterns (or annular structures). The second part of the thesis is concerned with the cooperative transport of a heavy object. The last part of thesis will be on foraging. The robot platform used is the e-puck miniature mobile robot [8]. It has two differential wheels, a directional colour camera pointing forward, and eight proximity sensors distributed around the robot's perimeter.

2. SEGREGATION BEHAVIOUR

In the segregation task, we focus on the problem of making a swarm of physical robots self-organize into an annular structure [3]. When a mixture of particles with different attributes undergoes vibration, a segregation pattern is often observed. For example in muesli cereal packs, the largest particles—the Brazil nuts—tend to end up at the top [9]. For this reason, the phenomenon is known as the Brazil nut effect.

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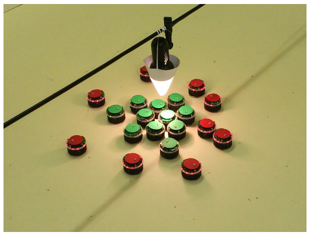

Figure 1: Task 1: spatial segregation. 20 e-puck robots have organized into a centre-periphery pattern around a light bulb. Robots with green and red top markers emulate disks of radius 8 cm and 16 cm, respectively. Each robot's motion is governed by a combination of three components: (i) attraction towards the light bulb, (ii) random motion and (iii) repulsion from nearby robots.

In previous research [5], an algorithm inspired by the Brazil Nut effect was designed to produce segregation patterns in swarms of simulated agents that move on a horizontal plane. This algorithm has been ported onto the e-puck. In a swarm of e-pucks, different robots mimic disks of different sizes. The motion of every robot is governed by a combination of three components: (i) attraction towards a point, which emulates the effect of a gravitational pull, (ii) random motion, which emulates the effect of vibration and (iii) repulsion from nearby robots, which emulates the effect of collisions between disks. The algorithm does not require robots to discriminate between other robots; yet, it is capable of forming annular structures where the robots in each annulus represent disks of identical size. A set of experiments have been performed with a swarm of 20 physical e-pucks. The results obtained in 100 trials of 20 minutes each show that the percentage of incorrectly-ordered pairs of disks from different groups decreases as the size ratio of disks in different groups is increased. In our experiments, this percentage was on average below 0.5% for size ratios between 3.0 and 5.0. Moreover, for these size ratios, all segregation errors observed were due to mechanical failures that caused robots to stop moving. Figure 1 shows a typical segregation pattern in the experiments.

3. COOPERATIVE TRANSPORT

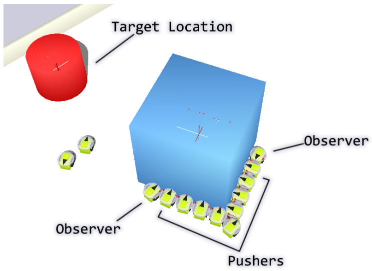

Figure 2: Task 2: group transport. Robots that are pushing a cuboid object near to the target location. The robots at both ends of the pushing group frequently check the direction of transport using their camera vision, while the other robots will focus on pushing the object.

The group transport task is about coordinating a group of robots to push a large object towards a target location. Numerous solutions to this problem have been proposed in the last two decades [6, 7]. The performance of these however typically deteriorates as the number of robots increases to more than a dozen. The cause of this is often said to be robot interference. In practice, this means that there are many robots but insufficient space to manipulate the object effectively. The situation is particular difficult when the object itself occludes the view of robots [4]. In this case, robots can benefit from division of labour and communication.

We have developed a simulation framework based on the Bullet Physics Library [2] and Enki Robot Simulator [1] to implement and verify the robot behaviour more efficiently. The robot behaviour was inspired by the division of labour in teams of humans pushing a large object: persons who can see the target location push the box only when the transporting direction needs to be corrected, while persons who can not see the target location simply push the box forward. Figure 2 shows a screenshot of the simulator and the two roles in this behaviour is shown. The decision making of the robot is programmed using a state-machine. In each state, a neural network controller is used to control the motion needed. A set of systematic experiments was conducted to evaluate the efficiency of the behaviour in simulation. The robots reside in a bounded arena of 5 m x 5 m dimensions. The object to be transported is a blue cube which is tall enough to occlude the target location. It is placed in the centre of the arena. The target location, a red cylinder, is located at a fixed distance. The robots start from random locations within a starting zone. The time used for the object to reach the target location was measured. The results show that the behaviour was reliable as long as there were a sufficient number of robots involved. However, the box moved on average by about 1 cm/s only, which is much slower than the pushing neutral speed of 7 cm/s which is the speed if there is no payload.

The behaviour is also implemented on the physical e-puck robot. To overcome some problems on the real system, parts of the behaviour had to be adjusted. Furthermore, a short-ranged communication method was developed to enable the robot to discriminate other robots and the object. By observation, the controller successfully made decisions about which role a robot should perform and all of the movement control neural networks were working as expected. Although it may take relatively long time compared to the distance travelled, the group of robots always succeeded in moving the object to the target location.

This study is still on-going. The behaviour will be further refined. Furthermore, the transport task maybe expanded. One possibility is to expand the task into a foraging task which means the cooperative transport happens in a more complex environment. For example, there may be obstacles or walls between the object. To achieve that, the capability of relaying the target location information to the transport group should be considered.

4. REFERENCES

[1] Enki robot simulator. Accessed on November, 2010, from `http://home.gna.org/enki/`, 2007.

[2] Bullet physics library. Accessed on December, 2010, from `http://bulletphysics.org/`, 2011.

[3] S. Camazine, J.-L. Deneubourg, N. R. Franks, J. Sneyd, G. Theraulaz, and E. Bonabeau. *Self-organization in biological systems.* Princeton Univ. Press, Princeton, NJ, 2001.

[4] R. Groß and M. Dorigo. Cooperative transport of objects of different shapes and sizes. In *Proc. of the 4th Int. Workshop on Ant Colony Optimization and Swarm Intelligence (ANTS 2004)*, volume 3172 of *Lect. Notes Comput. Sc.*, pages 106–117. Springer Verlag, Berlin, Germany, 2004.

[5] R. Groß, S. Magnenat, and F. Mondada. Segregation in swarms of mobile robots based on the Brazil nut effect. In *Proc. of the 2009 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, pages 4349–4356. IEEE Computer Society Press, Los Alamitos, CA, 2009.

[6] C. R. Kube and H. Zhang. Collective robotics: From social insects to robots. *Adaptive Behavior*, 2(2):189–218, 1993.

[7] M. J. Matarić, M. Nilsson, and K. T. Simsarian. Cooperative multi-robot box-pushing. In *Proc. of the 1995 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, volume 3, pages 556–561. IEEE Computer Society Press, Los Alamitos, CA, 1995.

[8] F. Mondada, M. Bonani, X. Raemy, J. Pugh, C. Cianci, A. Klaptocz, S. Magnenat, J.-C. Zufferey, D. Floreano, and A. Martinoli. The e-puck, a robot designed for education in engineering. In *9th Conf. on Autonomous Robot Systems and Competitions*, volume 1, pages 59–65. IPCB: Instituto Politécnico de Castelo Branco, 2009.

[9] A. Rosato, K. J. Strandburg, F. Prinz, and R. H. Swendsen. Why the Brazil nuts are on top: size segregation of particulate matter by shaking. *Phys. Rev. Lett.*, 58(10):1038–1040, 1987.

[10] E. Sahin. Swarm robotics: From sources of inspiration to domains of application. *Swarm Robotics WS 2004*, pages 10–20, 2005.

[11] E. Sahin. Swarm robotics: From sources of inspiration to domains of application. In E. Sahin and W. Spears, editors, *Swarm Robotics*, volume 3342 of *Lecture Notes in Computer Science*, pages 10–20. Springer Berlin / Heidelberg, 2005.