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Area Coverage in Two-Dimensional Grid Worlds Using Computation-Free Agents

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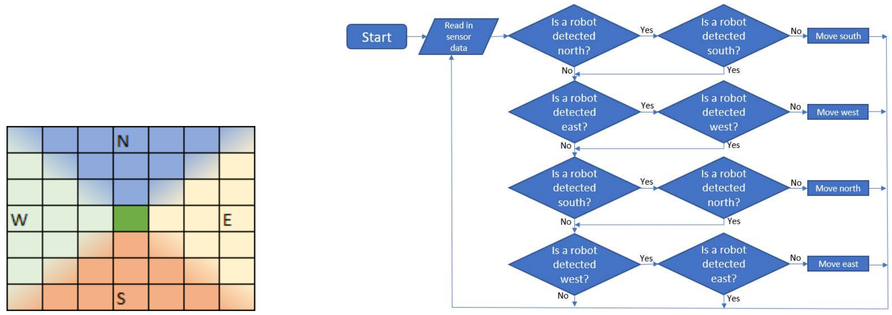
Abstract. This work proposes a novel solution to the problem of covering a bounded grid world using a swarm of robotic agents. The controller requires no run-time memory and only few, discrete sensory inputs. Two variants of the solution to the problem are studied, one effectively modulating the sensing range based on the agent's context. It is found that during the dispersion, the controller with sensing range modulation outperforms the default controller in terms of speed and evenness of the dispersion. Due to its simplicity, the solution could be realised on swarms of agents with ultra-low power and computational requirements, making it potentially relevant for large-scale swarm applications.

Keywords: Area coverage · multi-robot system · swarm robotics.

1 Introduction

The problem of area coverage concerns a group of robots, or mobile sensing units, that operate in a bounded environment, seeking to maximise the area that their sensors collectively monitor at any given time. Assuming simple, range-limited sensors and that all parts of the area to be monitored are of equal importance, one strategy for the group is to spread as uniformly as possible. In general, the types of sensors and computational resources can affect both the cost and performance of multi-robot coverage solutions. In some practical applications (e.g. search & rescue or monitoring pollution), cost-effective solutions for covering vast areas in limited time are desirable, prompting related research in the field of swarm robotics. Numerous distributed controller solutions have been proposed to the area coverage problem, which are relevant for swarms of robots. One of these employs the potential field method [3], which requires each robot to estimate the relative positions of other robots in its neighbourhood. A similar approach [4] requires each robot to move away from its k closest neighbours. Ramaithitima et al. [7] propose an approach that requires the robots to obtain only contact and bearing estimates. Recently, Özdemir [6] proposed a coverage controller that, when tested on a swarm of e-puck robots, outperformed a random walk controller. The approach was based on the "computation-free" control paradigm introduced in [2]. This paradigm assumes no run-time memory. The robots simply map a discrete sensory input to the output, which was used to set the continuous velocities of the e-puck robot's wheels.



(a) (b)

Fig. 1. Distributed area coverage solution: (a) The agent (in centre) has four contact sensors (not shown) and four optical sensors, with the respective field of view indicated (bi-coloured cells are within the range of multiple sensors). Here the range of the optical sensors is of length three. (b) Flowchart for the memoryless coverage controller.

The present work considers the problem of covering a bounded, 2-D grid world using a swarm of robotic agents. It presents a computation-free controller which to the best of the authors knowledge is currently the only memoryless solution to the multi-robot area coverage problem in grid environments.

2 Design

The environment is a bounded 2-D grid world comprised of square cells. Time is discrete, and one robot is updated at a time. The robots are updated in the same order during the run, but this order is randomised between runs.

The robots are modelled as squares the size of a cell in the grid, and are based off the MIT modular re-configurable robot M-Blocks [8]. Each time step, a robot either moves to an empty neighbouring cell in its von Neumann neighbourhood, or remains in place. Each robot is assumed to have activated an LED light that can be seen from all directions. On each face, it has an optical (light) sensor and a contact sensor. The light sensor detects any other robot within its respective range (see Figure 1(a)). The environment boundary cannot be detected, but restricts movement. The overall setup is similar to the setup in [5].

All robots execute an identical controller (see Figure 1(b)). The basic idea is that the robot moves into a direction where no robot is currently detected (i.e. no direct neighbour and no light) and that is opposite to a direction in which a robot is currently detected (i.e. direct neighbour or light). If no such direction exists, the robot remains in its current cell. As an alternative solution, a mechanism for sensing range modulation is explored. In this case, the robot first checks whether it is in contact with another robot on any face. If this is the case, it does not probe its optical sensors. This modulates the sensing range between the full optical range (when the robot has no contact neighbours) and the contact range.

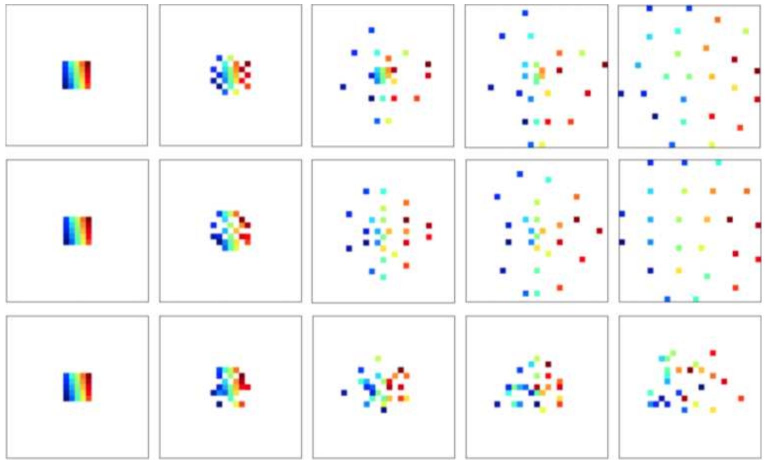


Fig. 2. Swarm dispersion after 0, 1, 6, 10 and 30 cycles with sensing range modulation off (first row) vs on (second row) vs random walk (third row). Each coloured square represents a robot.

3 Results

Each robot is said to cover all of the cells within its sensing range, as well as the cell it resides in. Area coverage is defined as the number of cells covered by all the robots collectively at a given time.

A square environment of 25×25 cells is considered. It contains 25 robots, each with a sensing range of 4. Figure 2 (first and second rows) shows two typical runs, one with the default controller, the other with sensing range modulation activated. For the swarm without sensing range modulation, it can be seen that the outermost robots in the swarm disperse relatively evenly, but the inner robots in the swarm do not disperse well. The initial square configuration of the robots achieved a coverage of 27.0%. The mean amount of coverage in the 10th time-step over 10 runs of this simulation was 82.8%. For the swarm with sensing range modulation, it can be seen that the robots disperse more evenly. The mean amount of coverage in the 10th time-step over 10 runs of this simulation was 89.9%. Comparatively, in the same situation a uniform random walk achieved a mean of 52.5% coverage over 10 runs. Figure 2 (third row) shows a typical run using this random walk.

Using 25 robots with a sensor range of 5 in a 35×35 cells environment, the swarm without sensing range modulation takes longer to disperse than the swarm with sensing range modulation (see Figure 3). However, when the desired level of coverage is low, both swarms perform equally well, presumably as at the start of the run they spread out at the same rate. After initial dispersion, the swarm with sensing range modulation spreads out at a faster rate. At the start, when the robots are still in contact, the different behaviour as a result of the sensing range modulation may put the swarm in a better configuration to

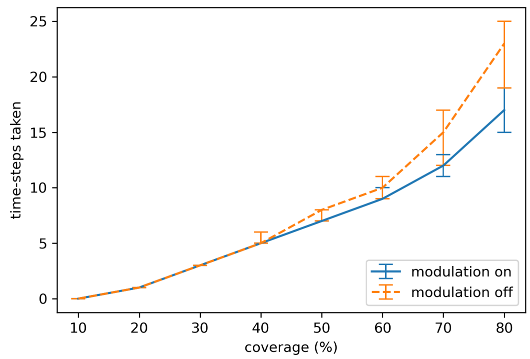


Fig. 3. Comparison of the time taken for different levels of coverage to be achieved with sensing range modulation on vs off. Runs for different levels of coverage are independent. Error bars indicate the range.

spread out faster later. When increasing the environment size further, without increasing either the number of robots or their sensing range, the robots disperse until out of range of one another, possibly resulting in uneven distributions [1].

4 Conclusions

This work proposed a novel solution to the problem of covering a bounded grid world using a swarm of robotic agents. To the best of our knowledge, it is the simplest solution to this problem so far. The controller requires no run-time memory and only few, discrete sensory inputs. The agents lack global information, and do not communicate. Two variants of the solution were studied, one effectively modulating the sensing range based on the context. It was found that during the dispersion, the controller with sensing range modulation outperformed the default controller. In particular, the sensing range modulation increases the speed and evenness of the dispersion. Due to its simplicity, the coverage solution could be realised on swarms of agents with ultra-low power and computational requirements, making it potentially relevant for large-scale swarm applications. In the future, the solution could be implemented on a physical platform such as the M-Blocks robots [8], and tested in more realistic scenarios.

References

1. Dhesi, A.: Covering an Area With a Swarm of Low Computation Robots. Bachelor's thesis, Department of Automatic Control and Systems Engineering, The University of Sheffield, UK (2021)
2. Gauci, M., Chen, J., Li, W., Dodd, T., Groß, R.: Self-organized aggregation without computation. International Journal of Robotics Research **33**(8), 1145–1161 (2014)

3. Howard, A., Matarić, M.J., Sukhatme, G.S.: Mobile sensor network deployment using potential fields: A distributed, scalable solution to the area coverage problem. In: Proceedings of the 6th International Symposium on Distributed Autonomous Robotic Systems (DARS 2002). pp. 299–308. Springer, Berlin, Germany (2002)
4. McLurkin, J., Smith, J.: Distributed algorithms for dispersion in indoor environments using a swarm of autonomous mobile robots. In: Proceedings of the 7th International Symposium on Distributed Autonomous Robotic Systems (DARS 2004). pp. 399–408. Springer, Tokyo, Japan (2007)
5. Özdemir, A., Romanishin, J.W., Groß, R., Rus, D.: Decentralized gathering of stochastic, oblivious agents on a grid: A case study with 3d m-blocks. In: International Symposium on Multi-Robot and Multi-Agent Systems, MRS 2019. pp. 245–251 (2019)
6. Özdemir, A., Gauci, M., Kolling, A., Hall, M.D., Groß, R.: Spatial coverage without computation. In: 2019 IEEE International Conference on Robotics and Automation (ICRA). pp. 9674–9680. IEEE (2019)
7. Ramaithitima, R., Whitzer, M., Bhattacharya, S., Kumar, V.: Sensor coverage robot swarms using local sensing without metric information. In: 2015 IEEE International Conference on Robotics and Automation (ICRA 2015). pp. 3408–3415. IEEE (2015)
8. Romanishin, J.W., Gilpin, K., Claici, S., Rus, D.: 3D M-Blocks: Self-reconfiguring robots capable of locomotion via pivoting in three dimensions. In: 2015 IEEE International Conference on Robotics and Automation. pp. 1925–1932 (2015)