Stigmergic Coverage Algorithm for Multi-Robot Systems (Demonstration)

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ABSTRACT

We demonstrate the realization of stigmergic coverage for multi-robot systems. Compared to current state-of-the-art algorithms for multi-robot coverage, our Stigmergy-based Coverage algorithm (StiCo) has several key advantages. In particular, it does not need direct robot-robot communication. Moreover, this algorithm does not require any prior information about the environment. Simulation results illustrate robustness, scalability and simplicity of the algorithm.

Categories and Subject Descriptors

I.2.9 [**Artificial Intelligence**]: Robotics—*Autonomous vehicles, Commercial robots and applications*

General Terms

Algorithms, Design

Keywords

multi-robot coverage, stigmergy, multi-agent systems

1. INTRODUCTION

Recent years have shown a rapidly growing interest in the automated coverage of complex, large and unknown environments through teams of cooperating autonomous robots. The main reason for this interest in multi-robot coverage lies in its broad range of potential applications in civil, industrial and military domains.

Current research mainly focuses on graph-based approaches (e.g. [1–3]) and Voronoi-based approaches (e.g. [4, 5]). The basic idea underlying graph-based approaches is to model the subregions of an environment and connections between them with a graph and develop graph search algorithms (e.g. DFS, BFS) for exploration/coverage of this graph. A practical drawback of graph-based approaches, however, is that they require to map the environment to a graph-like structure, which is computationally expensive and inapplicable in complex large environments. In contrast, Voronoi-based approaches aim at spreading out the robots over an environment by positioning each robot at the centroid of its Voronoi cell. Unfortunately, Voronoi-based methods inherently suffer from high computational complexities, too. In addition, these methods require direct communication among robots which is not applicable in limited-communication environments.

This paper investigates an alternative approach to multi-robot coverage, called StiCo, which is based on the principle of stigmergic (pheromone-type) coordination as known from ant societies. Compared to graph-based approaches, our approach is a model-free coverage algorithm implemented on memory-less simple robots. Moreover, while our approach avoids the complexity of available Voronoi-based approaches, it achieves a Voronoi-like segmentation and coverage of the environment in a very robust way on the basis of indirect communication only. The main characteristics of our approach are its simplicity, robustness, scalability and flexibility, as described below and illustrated in the video demo available at:
http://swarmlab.unimaas.nl/papers/aamas-2012-demo-2

2. THE StiCo APPROACH

The StiCo approach follows the principle of indirect, pheromone-based coordination. StiCo assumes that there is a group of robots which have the capacity to communicate indirectly by depositing markers (also called pheromones) in the environment for noticing margins of their territories to the others. In addition, each robot is equipped with two simple sensors (in the front-left and front-right directions like an ant antenna), capable of detecting immediate pheromones.

It is demonstrated that the developed coverage algorithm causes the environment to be partitioned into smaller regions (called as *robot territory*), while margins of each region are guarded by an individual robot. StiCo uses pheromone detections to recognize the already covered areas and guide the robots to uncovered environments. This algorithm does not need any memory or computation ability.

In SitCo, each robot starts to move on a circle with a predetermined radius. Based on the circling direction (CW or CCW), one sensor would be considered as the interior sensor and the other as the exterior one. When the interior sensor detects pheromone, the robot changes circling direction immediately as shown in Figures 1a,1b. Otherwise, if exterior sensor detects pheromone, the robot rotates in the same direction until it doesn't detect pheromone any more. Moreover, the amount of pheromone deposited by each robot

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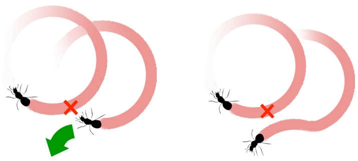
is adjusted based on pheromone evaporation rate, in a way that robots do not collide with their own pheromones.



(a) (b)

Figure 1: StiCo coordination principle (a) before pheromone detection (b) after pheromone detection

This simple algorithm is detailed in Algorithm 1.

Algorithm 1 StiCo Algorithm

Require: Each robot can deposit/detect pheromone trails
  Initialize: Choose circling direction (CW/CCW)
  loop
    while (no pheromone is detected) **do**
      Circle around
      deposit pheromone
    end while
    if (interior sensor detects pheromone) **then**
      Reverse the circling direction
    else
      while (pheromone is detected) **do**
        Rotate
      end while
    end if
  end loop

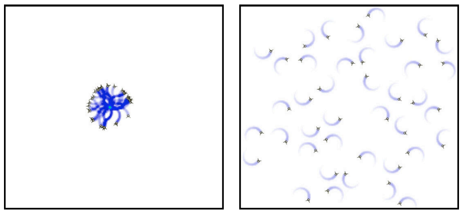
3. SIMULATION RESULTS

In this section, we demonstrate the evolution of our simple StiCo algorithm on a robotic swarm of identical members in a $40m \times 40m$ field. Simulations are implemented in Microsoft Visual C++. The pheromones are simulated with a high resolution, equal to 300×300 and the evaporation rate is $10units/s$. The linear velocity of each robot is $2m/s$, and the angular velocity is set to $\pm 1.0rad/s$. Each robot deposits 25units of pheromone in each iteration, and has two pheromone-sensors which can detect pheromones from a distance of $2m$. We pay careful attention to numerical accuracy and optimization issues in the pheromones update policy. Execution of coverage algorithm for 40 robots which move based on StiCo is illustrated in Figure 2.

In order to demonstrate potential capabilities of this simple algorithm, we consider a non-convex unknown environment as shown in Figure 3a. This environment can represent a devastated area after earthquake, or a street map in an emergency condition. 40 robots are initiated at the center of the environment. The coverage steps are illustrated in Figures 3a-3c. (In this simulation artificial pheromones are deposited on the margins of obstacles to make them detectable for robots).

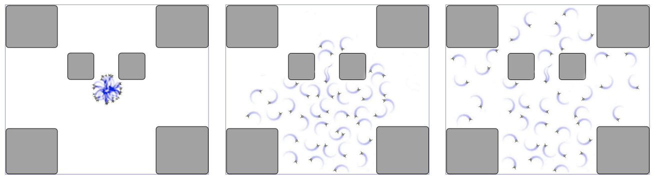
4. CONCLUSIONS AND FUTURE WORK

In this paper we addressed a coverage problem called StiCo for a group of robots which coordinate indirectly via ant-



(a) (b)

Figure 2: Evolution of StiCo in a simple environment (Blue shadows are deposited pheromones) (a) Initial snapshot (b) Final snapshot



(a) (b) (c)

Figure 3: Evolution of StiCo in a complex environment. (a) Initial snapshot (b) Intermediate snapshot (c) Final snapshot

like, stigmergic communication. We assumed that robots can not communicate directly with each other. Therefore, a stigmergic communication through depositing pheromones in the environment were proposed. Fully distributed motion policies were designed which concluded to robust coverage of the unknown environment. Efficiency of StiCo algorithm was demonstrated with illustrative simulations.

As future work, we are planning to improve the behavior of presented algorithm and develop a comprehensive probabilistic framework for StiCo which can help us to prove its efficiency in mathematical form. Moreover, we are investigating how to implement StiCo on real swarms.

5. REFERENCES

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